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SLAG DISPOSAL
SITE INVESTIGATION
AT
ALGOMA STEEL CORP.,
VOLUME I

MARCH 1992



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ADDENDUM
TO
BEAKS ALGOMA STEEL CORPORATION LIMITED
SLAG DUMP REPORT

In the report, references are made to the Ontario Drinking Water Objectives and Provincial Water Quality Objectives/Guidelines for comparison purposes. These objectives and guidelines are for application to drinking water supplies to protect human health or ambient surface water quality to protect aquatic life and recreation.

While they are useful for comparison purposes they are designed to be applied to drinking water supplies and ambient surface waters beyond property boundaries. These objectives/guidelines will be used to determine the success of ongoing abatement programs such as the remedial measure implemented by Algoma Steel to eliminate discharges of BTX and PAH from the Algoma Steel Slag Dump.

The Beak Report accurately reflects the situation which existed during the period when the slag dump study was being completed (i.e. 1988-90). Since that time however, a number of initiatives have been undertaken by Algoma Steel, which should result in significant improvement to the environment.

The Beak Report identified the Algoma Slag Dump site as contributing 3% of the total chloride load, 15% of the BTX load and 32% of the PAH load to the St. Marys River.

With the Ministry of the Environment's emphasis on their 3 R's Program, Algoma Steel has been recycling wastes which were formally deposited within their slag dump:

- Although chlorides are not identified as a problem in the St. Marys River, every reasonable effort should be made to reduce the discharge of chlorides to the St. Marys River. Algoma's waste pickle liquor, the major source of chlorides from the slag dump has in the past been disposed of within the slag dump. Algoma has instituted a program of recycling the pickle liquor (which is used as a phosphorous removal agent in Southern Ontario sewage treatment plants) to the point where 43% of the material was shipped to Southern Ontario in August, 1991. Algoma's current plans are for phased increases in the shipments which will reach 95% pickle liquor recycle by the end of 1992.
- Decanter Sludge (a source of PAHs and BTXs) is now combined with coal and recycled to the Coke Ovens.
- Coal tar spills are no longer disposed of in the slag dump, but returned to process where they become part of Algoma's product.

- Previously deposited or spilled coal tar is believed to be a major source of PAH and BTX discharges from the slag dump. Because 98% of BTXs and PAHs, originating within the slag dump, report to the St. Marys River by way of Bennett Creek, remedial measures are being concentrated in this area. To reduce the discharge levels, every effort must be made to recover free coal tar. In the last year, Algoma has implemented two programs to remove coal tar from the environment:

- during the summer of 1991, the Bennett Creek Coal Tar Collection System was completed. The system consists of a coal tar interceptor/collector system designed to halt the migration of coal tar, from Spring Creek and environs, to Bennett Creek. As well, a berm and collector system has been installed within the Bennett Creek itself, to act as a back-up, to ensure that no free coal tar enters Algoma's Slip and the St. Marys River. A deep collector well has also been constructed to recover free coal tar at depth.
- As conditions of the Certificate of Approval for the Bennett Creek Coal Tar Collection System, Algoma is required to document the quantities of coal tar recovered and returned to process, as well as monitor the quality of Bennett Creek to ascertain the success of the remedial action program. Included in the monitoring program is the collection of whole water samples which would include dissolved coal tar products, free coal tar products and coal tar products associated with suspended matter.
- Algoma has also commenced a program of recovering coal tar from a coal tar pond located near the centre of the slag dump. This pond is believed to be contributing to the PAH/BTX load entering the Base Line Ditch and Bennett Creek. This project will hopefully be completed by the end of 1992.

Ongoing Activities Relating to the Recommendations of the Beak Report

To ensure the integrity of the City's municipal drinking well water supplies, the Drinking Water Surveillance Program, which involves the monitoring of conventional, as well as organic compounds, will be continued.

The MISA monitoring program required the loadings from municipal and industrial point and non-point sources be monitored for a wide range of contaminants, including organics. Now that these data have been validated and made available, the environmental significance of other constituents from the Algoma Slag site can be assessed.

Algoma's monitoring program, developed in accordance with the Certificate of Approval requirements for the Bennett Creek remediation program, will provide a load measure of the PAH and BTX discharges.

Periodic ongoing St. Marys River studies to gauge the success of ongoing abatement programs will be targeted to evaluate the success of the slag dump remedial program.

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ALGOMA STEEL CORPORATION
VOLUME I

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Report Prepared By:

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Guelph, Ontario

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EXECUTIVE SUMMARY

Study Objectives and Approach

The Ontario Ministry of the Environment (MOE) identified the Algoma Steel slag disposal site (Algoma slag site) in Sault Ste. Marie, Ontario as a potential source of dissolved constituents to the St. Marys River which connects Lake Superior and Lake Huron. Beak Consultants Limited (BEAK), in association with Terraqua Investigations Ltd. and Atomic Energy of Canada Limited, were contracted by the MOE to conduct a comprehensive investigation of the Algoma slag site to quantify the flux (or loading rates) of constituents of environmental concern from the site and to identify their significant pathway(s). Previous studies have identified elevated levels of some metals and polycyclic aromatic hydrocarbon (PAH) compounds in the St. Marys River, and these were included in an extended list of chemical constituents for study and evaluation at the Algoma slag site. The purpose of the study was to identify the significant constituents, if any, identify their respective pathways and compare loading rates from the site to those associated with monitored effluent discharges to the St. Marys River. To meet these objectives, the investigation was planned as a multi-faceted study which included:

- an historical review of waste disposal practices and identification of constituents of environmental concern related to specific wastes;
- a leachate study of individual waste types as a means of identifying constituents of environmental concern;
- a hydrogeologic study to determine groundwater flow pathways (both shallow to examine discharge to surface water, and deep within the sandstone bedrock which is a regional water supply aquifer), the quality of groundwater migrating off the Algoma slag site, and finally to estimate the flux of dissolved constituents discharging to the St. Marys River and on-site creeks through the groundwater system;

-
- a seepage study to verify the existence of groundwater discharge zones through the St. Marys River sediments adjacent to the Algoma slag site; and
 - a surface water study to quantify flow rates and loadings via surface drainage to the St. Marys River.

The field investigation was initiated in June 1988 with (1) drilling and installation of 33 monitoring wells on the Algoma slag site, closely followed by (2) the establishment of surface water monitoring stations in creeks around and on the site, (3) the installation of river bed mini-piezometers and seepage meters along the river's shoreline, and (4) the installation of creek-bed mini-piezometers in creeks on and around the site. Data have been collected on groundwater elevations, hydraulic conductivities of subsurface materials, stream-flow rates, and seepage rates. Additionally, numerous water samples have been collected and analyzed for selected constituents.

This report presents all data collected during this investigation. This data, together with data from previous hydrogeologic investigations of the site and data from adjacent areas, were used to determine the subsurface geology, groundwater flow conditions and surface water flow rates, all of which are described in this report. The extensive water quality data collected during this investigation are summarized in this report and are used, together with the flow information, to estimate the off-site flux of dissolved constituents in the groundwater and surface water. The mass flux estimates are summarized in this report and compared to loadings via effluent discharge to the St. Marys River.

Leach Testing

The leachates from nine waste/by-product materials, four contaminated subsurface soils and two uncontaminated subsurface soils were analyzed to determine which constituents of environmental concern could leach from these materials and potentially enter water courses or groundwater. The constituents identified by leach testing were PAHs, metals, phenols,

cyanide, ammonia and acid. Volatile organic compounds, although not specifically identified during the leach testing because of the testing method employed, were also targeted as constituents with the potential to leach from the waste materials after consideration of the chemistry of the waste material.

Hydrogeologic Study

The hydrogeologic study showed that the groundwater flow system behaves as expected, with lateral flow generally from north to south (toward the St. Marys River). Components of vertical flow are upward from the bedrock to the natural unconsolidated sediments everywhere except within the central area of the Algoma slag site where downward gradients occur. The downward gradients in this area are probably the result of surface ponding and the disposal of pickling liquor nearby. Discharge of groundwater affected by wastes on-site occurs along the St. Marys River shoreline, into the West Davignon Diversion Channel, the ditch along Baseline Road, Bennett Creek and Spring Creek.

Groundwater in areas adjacent to likely sources of chemical constituents of environmental concern was characterized by high concentrations of PAHs; benzene, toluene and xylenes (BTX); sulphate; cyanide; fluoride; chloride; ammonia; phenols; and metals. Shallow groundwater in areas adjacent to the site perimeter or on-site creeks was characterized by elevated chloride, sulphate, alkalinity and calcium concentrations, and by elevated pH values (pH = 9 to 12 except in the vicinity of the pickling liquor disposal area). Except for iron and manganese, most metals concentrations were low; however, several metals were present at concentrations greater than drinking water and aquatic life guidelines. Phenols and cyanide (at levels in excess of aquatic life guidelines), BTX and PAHs occur in shallow groundwater samples from most site areas.

Hydraulic gradients show that flow in the bedrock aquifer occurs from Wallace Terrace Road (location A7) toward the slag site. Furthermore, vertical gradients are directed upward from

the bedrock which would prevent the downward movement of shallow site-affected groundwater to the confined aquifer. The chemistry of water samples from the bedrock wells north of the site (A7-1 and A4-1) suggest that the deep groundwater has not been affected by shallow site-affected groundwater. The hydraulic gradients and water chemistry indicate that there is almost no possibility of groundwater migrating from the Algoma slag site toward the city water supply wells to the north of Wallace Terrace Road.

The shallow mini-piezometers in the West Davignon Diversion and in the Baseline Road ditch confirm the upward flow of groundwater through the stream bed sediments. The chemistry of water samples obtained from the mini-piezometers is similar to the chemistry of the shallow groundwater from the site. These creeks are discharge areas for shallow site-affected groundwater.

St. Marys River Seepage Study

The St. Marys River seepage study confirmed that groundwater fluxes are upward through the river sediments, and that shallow sediment water was chemically similar to nearby shallow groundwater from the nearby areas of the Algoma slag site.

Surface Water Study

The surface water study confirmed that there was very little possibility of overland runoff on the Algoma slag site. The on-site and peripheral creeks (ditches and streams) are the only significant pathways for constituents to leave the site via surface water. Flow measurements and water quality analyses confirm that the flow in the Baseline Road ditch and in Spring Creek originates entirely from groundwater discharging from the Algoma slag site but that Bennett Creek and the West Davignon Diversion receive only a small relative contribution of flow from groundwater discharge from the site.

Summary of Mass Fluxes

The estimated flux of dissolved chemical constituents from the Algoma slag site to the St. Marys River was compared with loading rates to the St. Marys River from point (e.g. effluent discharges) and non-point (e.g., stormwater runoff) sources. The Algoma slag site contributes negligible amounts of the total load of total phosphorus, cyanide, phenols, copper, iron and zinc to the St. Marys River. The site contributes 3% of the total chloride load and, more significantly, 15 and 32% of the BTX and PAH loads respectively. The BTX and PAH loads do not account for the migration of separate phase tarry materials containing high concentrations of these constituents. Migration of tarry materials in creek beds or through the subsurface would significantly increase the PAH and BTX loading to the St. Marys River.

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1.0 INTRODUCTION

1.1 Study Background

In 1980, a Health and Welfare Canada study identified the raw water intake for Sault Ste. Marie as having the highest concentration of polynuclear aromatic hydrocarbons (PAHs) of all Great Lakes water intakes. At that time, the intake was located in the St. Marys River downstream of the Algoma slag site, but has since been relocated approximately 12 km upstream of the site. During 1984/85, the Ontario Ministry of the Environment (MOE) Water Resources Branch undertook a sediment and biomonitoring study of the St. Marys River adjacent to and downstream of the slag site. PAHs were detected in clams exposed adjacent to the slag site. Previous sampling of monitoring wells on-site revealed the presence of PAHs in groundwater at concentrations up to 265 µg/L (Geocon, 1983). The non-point source working group of the Upper Great Lakes Connecting Channel Study of the MOE identified the slag disposal site as a suspected source of heavy metals and PAHs in the St. Marys River and recommended further investigation to assess actual environmental impacts (Remedial Action Plan, St. Marys River, 1987).

Beak Consultants Limited (BEAK) was contracted by the MOE to complete a comprehensive study of the potential impacts of contaminants released from the Algoma Steel slag disposal area in Sault Ste. Marie, Ontario. The study which is reported here considered the potential release of constituents associated with the wastes and by-products to groundwater and surface water, and the effects on local municipal wells and on the St. Marys River. The area of investigation is shown on Figure 1.1. The potential impact of the slag disposal site on the Goulais and Steelton water supply wells (Figure 1.2) was also of concern because traces of PAHs were detected in the Steelton well water in 1984 (MOE memo from W. Mass to G.J. La Haye, 12 April 1985).

1.2 Site History

The Algoma Steel Corporation Limited (Algoma) has operated a steel mill complex in Sault Ste. Marie, Ontario, since the late 1800s. The plant is situated on the shoreline of the St. Marys River on the west side of the City of Sault Ste. Marie (Figure 1.1). Algoma has used an area of about 400 ha adjacent to the shoreline for the disposal of slag and other miscellaneous wastes since operations began at the turn of the century.

Dumping of molten and granulated slag on the natural ground surface commenced in the northeast corner of the dump site resulting in slag thicknesses of 3 to 21 m. As dumping progressed, dykes were constructed off-shore and the inlying pond was filled with slag to a level 1.5 to 3 m above the river. The dumping of slag past the shoreline has resulted in a 500 m extension of the land past the original shoreline. No infilling has occurred since 1982; however, slag disposal is ongoing. Excavation of slag for reprocessing is presently occurring in two pits located in the north part of the slag dump.

The southwest corner of the Algoma slag site was is now an aggregate loading zone operated by A.B. McLean Sand and Gravel. A dock was constructed by sinking an old ore carrier offshore and was used as a platform from which river sediments are dredged. A lagoon once located on the southwest corner has been filled with sediments obtained during dredging of the headrace for the Great Lakes Power Generating Station, and which are contaminated by zinc, oil and grease.

A former Domtar facility was located 500 m north of the St. Marys River adjacent to Spring Creek (Figure 1.1). The 4 ha facility began processing tar by-products from Algoma in 1929. Algoma had a coking by-product storage and handling area just east of the Domtar facility. Pitch beds were located on ground surface in this area.

A former coke gas purification plant was located on Algoma's property north of Base Line Road west of Goulais Avenue. The site is now a parking lot.

Spring, Bennett and West Davignon Creeks once constituted the major surface water drainage features at the Algoma site. All three creeks are now rechannelled and diverted to the west and northeast of the slag site. Figure 1.1 is an aerial photograph of the site on which the surface drainage and original shoreline are indicated.

1.3 Purpose and Scope

The study was a comprehensive examination of the Algoma slag disposal site, adjacent land masses and adjacent river bed sediments to:

- determine the direction, quality and quantity of leachate and surface runoff migration from the slag site;
- determine which critical receptors are, or have the potential to be, impacted by these discharges; and
- relate the impacts of these discharges (impacting on the groundwater, surface water and/or biota) to contaminants discharged from other documented sources throughout the Algoma Steel Complex.

The primary objective of this study was to determine whether or not the slag disposal site represents an environmental threat. There were, however, two aspects of this objective which were addressed. The first and primary aspect involved the determination of whether or not contaminants may have migrated, or are potentially migrating, toward the municipal wells. The secondary issue concerns the question of whether or not dissolved contaminants are migrating from the slag site into the St. Marys River and whether these pose a potential environmental threat.

This report presents the results of the measurements and chemical sampling completed in the summer of 1988 through spring of 1989. The purpose of this report is to present interpretations of the direction, quality and quantity of leachate and surface runoff, to determine the mass loading from groundwater and surface water from the slag site to the St. Marys River, and to compare these with point discharges to the St. Marys River.

1.4 Study Approach

The purpose of the study was to identify the significant contaminants, if any, identify their respective migration pathways and compare contaminant loading rates from the "uncontrolled" sources to those associated with monitored effluent discharges ("point sources") to the St. Marys River. To meet these objectives, the investigation was planned as a multi-faceted study which included:

- an historical review of waste disposal practices and identification of contaminants related to specific wastes;
- a leachate study of individual waste types as a means of identifying significant quantities of contaminants;
- a hydrogeologic study to determine groundwater flow pathways (both shallow to examine discharge to surface water, and deep within the sandstone bedrock which represents a regional water supply aquifer), contaminant concentrations in groundwater migrating off the slag site, and finally to estimate the flux of dissolved contaminants discharging to the St. Marys River and peripheral creeks through the groundwater system;
- a surface water study to quantify flow rates and contaminant loadings via surface drainage to the St. Marys River; and
- a seepage study to verify the existence of groundwater discharge zones through the St. Marys River sediments adjacent to the Algoma slag site.

The major effort in this study is being expended to examine the direction, quality and quantity of leachate migrating from the slag site. The flux of key chemical constituents from the slag site to the St. Marys River is determined for both groundwater and surface water components and forms the basis for the study approach.

A comprehensive hydrogeologic investigation was conducted with the aim of precisely defining the local groundwater flow conditions and contaminant concentrations within the system. Groundwater fluxes and contaminant concentrations were used to estimate the flux of key chemical constituents into the St. Marys River and slip area.

A number of other studies were used to supplement the assessment of potential contaminant migration into the St. Marys River. These include an investigation of the seepage rates through the river bed by Dr. D.R. Lee of Chalk River Nuclear Laboratories (AECL) and by surface runoff studies on and adjacent to the Algoma fill site. The river bed has been instrumented in areas targeted by reconnaissance surveys, and the shallow flow system controlling seepage into the river bottom were evaluated. The surface runoff studies concentrate on the transport of contaminants off-site as both dissolved and suspended loads. Seepage into the streams and creeks on-site and adjacent to the site were addressed to determine the relative importance of the groundwater recharge to these streams in transporting contaminants from the slag site and associated areas.

The purpose of the seepage studies was to verify the existence of contaminant fluxes through the sediment/water interface that are implied by the hydrogeologic investigation. Seepage flow rates and samples were collected using mini-monitoring wells and seepage meters in the river sediment to verify actual fluxes of chemical constituents through the groundwater/surface water interface in the St. Marys River. It is not envisioned that the seepage study is comprehensive enough to precisely estimate all of the groundwater input of contaminants to the river; instead, the seepage analysis and sampling were used to corroborate the estimated fluxes in some obvious areas which exhibit chemical and temperature anomalies suggesting significant groundwater seepage.

The overall approach to this study was to derive a mass flux for key contaminants in the system. In this way, high quality chemical data were used in conjunction with groundwater flow data, combined with information on seepage of groundwater and key chemical constituents into the St. Marys River. The concentrations of these compounds in the river sediments were determined as further assistance toward an overall estimate of what is being leached from the waste site and what is entering the water and sediments of the St. Marys River.

The potential connection between the slag site and associated groundwater mound, and the bedrock aquifer near the municipal wells was evaluated based on an assessment of whether or not hydraulic connection and gradients are appropriate for contaminant migration from the slag to the wells. Precise measurements of water levels, both for the watertable and the piezometric surface within the bedrock aquifer, were obtained to evaluate the hydraulic connection and horizontal and vertical gradients that define the flow system in that area.

1.5 Report Organization

The remainder of this report is divided into 8 chapters as follows.

- Chapter 2.0: Survey of Potential Contaminants - This chapter describes the waste materials disposed at the Algoma slag site and presents the results of chemical analyses of leachate from selected materials.
- The methods and results of three integrated studies are summarized in chapters:
 - Chapter 3.0: Hydrogeologic Study
 - Chapter 4.0: St. Marys River Seepage Study
 - Chapter 5.0: Surface Water Study

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- Chapter 6.0: Comparison of Mass Fluxes provides a summary of the contaminant fluxes via groundwater and surface water from the Algoma slag site to the St. Marys River. These fluxes are compared with fluxes from effluent discharge points to the St. Marys River.
 - Chapters 7.0, 8.0 and 9.0 contain conclusions, recommendations and references respectively.

2.0 SURVEY OF POTENTIAL CONTAMINANTS

2.1 Inventory of Wastes

A number of wastes and by-products are associated with the Algoma slag site. Table 2.1 provides a list of these materials, a description of each material, methods and rates of disposal or storage, and constituents of environmental concern. Disposal or storage areas for the materials listed in Table 2.1 are shown on Figure 1.1. The Certificate of Approval No. A560101 issued for the Algoma slag site states that 718,600 tonnes of solid and 66,800 tonnes of liquid are certified for disposal at the site annually.

The wastes and by-products listed in Table 2.1 result predominantly from either steel-making or coking processes. Slag from the blast furnace (BF) and basic oxygen furnace (BOF) operations and constitutes the major component (by volume) of the wastes and by-products. Both BF and BOF slags are primarily calcium aluminum silicate; however, BOF slag may contain traces of alloying elements. BF slag typically contains more lime than does BOF slag (Sirman Associates, 1985); therefore, leachate derived from BF slag tends to be of higher pH.

Other wastes and by-products associated with the steel-making processes are waste oils, pickling liquor, lime fines, filter cake, PCB-containing oils, pollution equipment abatement sludge and dunnage. Descriptions of these materials are given in Table 2.1. Excluding the waste oil and PCB-containing oils, these materials are disposed within the central area of the slag site (Figure 1.1). Process waters containing waste oil are pumped into a pond located in the central region of the slag site ("oil pond" on Figure 1.1). After separation of the oil and water, the oil phase is pumped into adjacent storage tanks. The separated oil was previously used for dust control; however, the potential for re-refining this oil is currently being evaluated by Algoma. PCB-contaminated equipment is stored within containers emplaced in steel vaults located adjacent to the St. Marys River shoreline.

Wastes and by-products related to the coking operation include coke tar, decanter sludge, gas line condensate and box oxide wastes. Although coal and coke are not wastes or by-products, they are stored in piles within a 24-ha area west of the boat slip and may also leach constituents. Decanter sludge and gas line condensate have been disposed of at the waste disposal site. There are no records of the disposal of tar or box oxide wastes at the slag disposal site, but these materials were found in the subsurface near the former Domtar and gas purification plants, respectively (CRA, 1988; GLL, 1988). Tar-like material was also found near the sludge dump during the site investigation.

Dredged river sediments are the only wastes stored on-site which are not directly related to the coking or steel-making operations. These sediments are located along the southwest portion of the site near the A.B. MacLean facility and contain zinc, oil, and grease.

2.2 Leach Testing

Leach tests were conducted as part of this study in an attempt to identify constituents associated with various wastes and by-products on-site which might have the potential to enter the groundwater. Identification of the key leachable constituents aided in the interpretation of their distributions, in groundwater and surface runoff. Analytical data are included in Appendix 4.

Previous data also available for review included Regulation 309 leachability tests that were performed on Algoma slag, filter cake and waste lime fines by Dofasco Inc. as part of the Canadian Steel Environmental Association's (CSEA) 1983 submission to the MOE regarding a Blueprint for Waste Management. The CSEA data are included in Appendix 4. The results of these tests (referred to as CSEA tests) are included in the discussion below.

2.2.1 Types of Leach Tests

Leach tests were conducted using methodology outlined in the Government of Ontario

Regulation 309. In this procedure, approximately 100 g of solid material is leached with up to 400 mL of 0.5 N acetic acid and later mixed with distilled water to give an approximate solid to liquid mass ratio of 1:10.

The standard MOE Regulation 309 test with acetic acid was conducted on selected materials from the Algoma slag site. Two additional types of tests, based upon Regulation 309 protocols, were conducted to simulate conditions on site:

- a hydrochloric acid leach test designed to simulate the infiltration of pickling liquor disposed at the acid dump, and
- an alkaline test, using a sodium hydroxide solution to simulate the movement of lime-affected groundwater on-site.

These tests were selected because many metals are much more soluble in acidic conditions, while some organic compounds, such as PAHs, are more readily leached by alkaline solutions.

2.2.2 Test Materials

Test materials consisted of "recent" wastes and products which were disposed, or stored, on the ground surface at the Algoma slag site. These materials, collected by spade, consisted of residues from the waste oil pond and acid dump, lime fines, BOF slag, filter cake, decanter sludge and contaminated coke (i.e., "contaminated" with coal). Four subsurface materials obtained during drilling of the boreholes and having distinctive organic odours were also selected for leach testing (Boreholes A1, A2, C4, D3). Additional leach tests were conducted on two samples of subsurface geologic materials having no organic odours (Boreholes A7 and B4) to determine which constituents could leach from the natural, presumably uncontaminated geologic material beneath the slag site.

Table 2.2 summarizes the leach test materials and the type of leach tests conducted on each material. Hydrochloric acid tests were conducted on recent materials located close to the pickling liquor disposal area. Filter cake and decanter sludge were thought to represent some of the most contaminated materials, so both hydrochloric and alkaline tests were performed on these materials. Oil pond residue and contaminated coke were selected for Regulation 309 leach tests since these were surface materials not likely affected by alkaline groundwater or pickling liquor, and for comparison to the leachate results obtained by CSEA for slag, lime fines and filter cake.

Alkaline leach tests were conducted on subsurface materials (except those from Boreholes A1 and A2) because these materials were in contact with alkaline groundwaters. Regulation 309 leach tests were conducted on materials from Boreholes A1 and A2, since these materials were in contact with neutral groundwater.

2.2.3 Chemical Analyses

Chemical analyses were performed on the leachates in two levels of detail. Table 2.3 lists the analytical parameters for each level. Level 1 included general parameters useful as indicators of other constituents while Level 2 parameters included target constituents of more significant environmental concern. Cyanide was added to selected Level 2 analyses. The analytical level for the leachates was selected to match the environmental constituents presumed to be associated with each material.

2.2.4 Test Results

The following sections provide a general description of the analytical results, in general, in terms of anions, metals and organics. A complete set of analytical results are given in Appendix 4.

Anions

Sulphate, the most abundant anion found in the leachates, was present at concentrations up to 40 mg/L in most leachates. Samples obtained from Boreholes A1 and A2, lime fines and acid pit residue produced acidic leachates containing sulphate concentrations ranging from 195 to 575 mg/L.

Chloride concentrations in leachates produced from Regulation 309 and alkaline tests were generally less than 8 mg/L, except for the CSEA Regulation 309 leachate from the lime fines (449 mg/L). Bromide concentrations in all leachates were below detection (0.5 mg/L). Fluoride concentrations, where analyzed, were less than 2 mg/L, except for the filter cake hydrochloric acid leachate which had a concentration of 7.3 mg/L.

Nitrate concentrations in all leachates were well below the drinking water limit (10 mg/L as N). Filter cake leachates contained nitrate of 0.10 to 2 mg/L. All other concentrations were less than or equal to 0.5 mg/L.

Total Kjeldahl nitrogen (TKN) concentrations, where analyzed, were up to 2.7 mg/L, except for alkaline leachate from decanter sludge which contained TKN at a concentration of 8.4 mg/L.

Filter cake, decanter sludge, and materials from Boreholes D3 and C4 were the only leachates (alkaline) which were analyzed for sulphide concentrations. These leachates contained sulphide concentrations at or below detection (0.05 mg/L), except for the decanter sludge leachate which had a concentration of 0.51 mg/L.

All leachates tested for cyanide (Table 2.2), except BOF filter cake, slag (CSEA results) and material from Borehole D3 contained cyanide at concentrations greater than the MOE Provincial Water Quality Objective (PWQO) of 0.005 mg/L. The alkaline leachate from the

decanter sludge contained cyanide at a concentration of 5.5 mg/L which was the only leachate with a cyanide concentration significantly greater than the drinking water limit (0.2 mg/L).

Metals

Calcium, magnesium and iron were generally the most abundant metals in the leachates. High calcium concentrations (up to 3,600 mg/L) occurred in leachates obtained from acid dump residue, filter cake, slag and lime fines. Iron concentrations were highest in leachates from acid dump residue (330 mg/L) and decanter sludge (HCl test, 60 mg/L).

Sodium, manganese, potassium and aluminum were generally the next most abundant metals present in the leachates, with concentrations up to 107, 36, 449 and 10 mg/L, respectively. Leachates from the oil pond and acid dump residues contained these high concentrations.

Cadmium and beryllium were not detected in the leachates. Concentrations of all other metals (see Table 2.3 for complete list) were generally less than 1 mg/L.

Table 2.4 summarizes the concentrations of metals in leachates which exceeded either drinking water or aquatic life guidelines. The natural geologic materials from Boreholes B4 and A7 produced alkaline leachates which contained metals concentrations which did not exceed any of the guidelines. All other leachates had at least two metal concentrations which exceeded the guidelines. Generally, alkaline leaches contained only copper and aluminum concentrations which exceeded aquatic life limits; however, material from Borehole C4 and decanter sludge leachates contained nickel and iron concentrations slightly above the PWQO's for these metals.

As expected, acidic leachates contained significantly more metals. The recent materials, including oil pond and acid dump residues, filter cake and decanter sludge, produced acidic leachates with metals concentrations which exceeded most aquatic life or drinking water

guidelines. Cadmium was the only metal for which the guidelines were not exceeded. The subsurface samples from Boreholes A1 and A2 produced leachates with manganese, copper, iron and aluminum concentrations which exceeded either aquatic life or drinking water limits (Table 2.4).

Phenols

Phenol concentrations in leachates are presented in Table 2.5. Concentrations were greatest in leachates obtained from the decanter sludge under both acidic (1.66 mg/L) and alkaline (2.5 mg/L) conditions. Leachates from oil pond residue and materials from Boreholes C4 and A1 had phenols concentrations of 0.032 to 0.062 mg/L. Phenols were not detected in acid dump residue, and some slag and filter cake leachates. All remaining leachates had phenols concentrations of 0.001 to 0.011 mg/L.

Polynuclear Aromatic Hydrocarbons (PAHs)

Oil and grease concentrations were analyzed in place of PAHs for samples from Boreholes B4 and A7, lime fines and BOF slag, because these materials were not expected to leach significant PAHs. Oil and grease concentrations were at or below detection (2 mg/L) for these leachates.

Total PAH concentrations are summarized in Table 2.5, while concentrations of the individual PAH compounds are provided in Appendix 4. Very low concentrations of total PAHs (0.4 to 3.0 µg/L) were detected in leachates from materials from Boreholes A2 and D3, acid dump residue, contaminated coke and filter cake (HCl leach). The filter cake, when leached under alkaline conditions, produced a leachate with substantially more PAHs (about 89 µg/L), which reflects the greater solubility of PAHs in waters with higher pH. Subsurface materials from Boreholes A1 and C4, oil pond residue and decanter sludge (both alkaline and HCl leaches) yielded leachates with total PAH concentrations over 375 µg/L.

Naphthalene was generally the most abundant PAH identified in the leachates; however, it is also the most soluble of the PAHs. Phenanthrene and acenaphthylene were the most abundant PAHs in filter cake (alkaline) and contaminated coke leachates, respectively.

2.2.5 Environmental Significance of Wastes and By-Products

Table 2.1 lists the environmental parameters which are characteristic of each waste type as identified by the leachate testing and consideration of the wastes' chemical compositions. The constituents of environmental concern are mainly PAHs, metals, phenols, cyanide, ammonia and acid. Although analysis of volatile organics is not practical on leachates because of the laboratory methods employed to produce the leachate, volatile aromatics are also likely to be associated with many of the wastes and by-products.

Under acidic conditions, environmentally significant concentrations of metals were leached from oil pond and acid pit materials, filter cake and decanter sludge. In alkaline conditions, most materials tested produced leachates with copper and aluminum concentrations above aquatic life guidelines.

3.0 HYDROGEOLOGIC STUDY

3.1 Introduction

The hydrogeologic study focused on the flow conditions and chemistry of the groundwater beneath the Algoma slag site. The objectives of this study were to determine the flux of dissolved constituents discharging from the site to the St. Marys River, and to determine the potential for groundwater from the site to affect water quality at the municipal water supply wells. To accomplish this, the following tasks were undertaken:

- Thirty-three monitoring wells were installed on the Algoma slag site. Groundwater samples from these wells were collected and analysed for constituents associated with the wastes disposed at the site and for general water quality parameters. This information was used to determine the hydrogeochemistry of the site and to estimate mass fluxes.
- Water elevations at monitoring wells installed during this investigation were determined at approximately monthly intervals. Water levels at several monitoring wells installed during previous investigations were measured during the spring of 1989 to supplement the monthly data. These data were used to determine groundwater flow conditions (hydraulic gradients) beneath the site.
- Single well hydraulic conductivity tests were performed in most of the monitoring wells installed during this investigation to determine the hydraulic conductivity of the subsurface material. This information, together with water level data, was used to determine groundwater flow conditions and the flux of groundwater to the St. Marys River and on-site creeks.

- Groundwater elevations were measured hourly at three deep wells (Domtar, A7-1 and A4-1) from 06 June to 07 July 1989 to determine the potential for groundwater movement in the regional aquifer from the Algoma slag site toward the municipal water supply wells.
- Eight groundwater samples were collected from the deep subsurface during the Winter 1989 and Spring 1989 sampling events for tritium analysis. This information was used to assist in determining the deep groundwater flow conditions.
- Three mini piezometer transects were installed across the creeks at the West Davignon diversion and Baseline Road ditch to determine the nature of the local groundwater flow conditions and seepage into the creeks.

Terraqua Investigation Ltd. assisted with the planning of the hydrogeologic study. Supervision of borehole drilling and monitoring well installation, hydraulic conductivity testing of monitoring wells and development of some monitoring wells was conducted by Terraqua personnel. Terraqua also provided the physical hydrogeologic data.

The hydrogeologic data presented in this chapter has been revised to include data collected from subsequent sampling rounds and previous investigations of the site.

The following sections describe the analytical and field methods used during this investigation, the general geology and hydrostratigraphy of the Algoma slag site, groundwater flow conditions and groundwater chemistry. Where possible, results from previous hydrogeologic studies (Geocon, 1983; ERA, 1988; GLL, 1988) have been incorporated with the results from this study. This chapter concludes by presentation of dissolved mass loadings to the St. Marys

River through groundwater pathways. This data is compared to other documented loadings to the St. Marys River in Chapter 6.0.

3.2 Methods

Field activities employed during the hydrogeologic study included drilling, monitoring well installation, soil and groundwater sampling, single well hydraulic conductivity testing, and installation and sampling of mini-piezometers. Details of the procedures are documented in Appendix 1; only a brief description of the methods is presented here. This section also provides a description of the chemical parameter selection procedure and approach for groundwater sample analyses.

3.2.1 Drilling, Soil Sampling and Monitoring Well Installation

Thirty-three monitoring wells were installed at the 22 locations shown on Figure 3.1. Borehole drilling and monitoring well installation was performed by All Terrain Drilling Company under the supervision of a Terraqua Investigations Ltd. hydrogeologist or geological engineer. Drilling and installation of all monitoring wells was conducted during the summer of 1988, except well B2-3 which was installed during the fall of 1988.

Hollow stem augering, using standard 10.8 cm (4 1/4 inch) inner-diameter (I.D.) augers, was employed at all but two of the boreholes. The required depth of penetration and difficult drilling conditions necessitated the use of the wet rotary drilling method at locations B2-3 and A7-1.

Special drilling techniques were employed at locations B2-1 and B2-3 to prevent contamination of the deep confined aquifer with materials from the overlying units. These techniques, described in detail in Appendix 1, were as follows. The upper aquifer was penetrated using a large diameter auger or drill bit. Large diameter casing was driven into the

top of the underlying aquitard and was then sealed using bentonite cement grout. Following partial setting of the grout, smaller diameter augers or drill bits were used to drill through the larger casing and into the underlying native materials. The locations of the casings are shown on the borehole and well construction logs for monitoring wells B2-1 and B2-3 (Appendix 2).

Subsurface soil samples were collected using either a continuous or split-spoon sampler. Cuttings were obtained using a wire mesh sieve where wet rotary drilling was used. All samples were photographed and geologically logged in the field. Representative subsamples were collected in glass jars for reference.

A single monitoring well was installed within each borehole. Nested monitoring wells were installed at several drilling locations and are comprised of two or three monitoring wells installed at varying depths in separate boreholes drilled within about three metres of one another. All monitoring wells (with the exception of A7-1, which had a steel casing) were constructed from 5 cm (2-inch) I.D. schedule 40 polyvinyl chloride (PVC) casing and slotted pipe. The final configurations of the monitoring wells in each of the boreholes are presented in Appendix 2.

3.2.2 Single Well Hydraulic Conductivity Testing

Single well hydraulic conductivity (or response) tests were conducted at all monitoring wells, except C2-2, A7-1 and B2-3, to determine the average *in situ* hydraulic conductivity of the geologic materials intersected by the well screen. C2-2 was dry so could not be tested. A7-1 was not tested as its large diameter made this impractical and B2-3 was not tested because it was installed several months after the other wells had been installed and tested. Tests were attempted at seven wells screened in the slag material along the shore line (B3, B4-2, B5, D1-2, D2, D3-2 and D4). The water levels could not be lowered by pumping in these wells because of the high hydraulic conductivity of the slag so the tests were not completed. The response test data were analyzed using the method of Hvorslev (1951). A description of this method is included in Appendix 1. Test results and calculations are included in Appendix 3.

3.2.3 Water Elevation Measurements

The tops of monitoring well casings and staff gauges installed during the summer of 1988 were surveyed by Bolan and Urso Ltd., Sault Ste. Marie, Ontario to provide precise reference elevations. During the spring of 1989, several existing monitoring wells installed by Geocon for a previous study (Geocon, 1983) were surveyed by BEAK personnel to reconcile the water level data obtained from the Geocon wells with that obtained from the wells installed for this investigation. The top of well B2-3 was also surveyed at that time because it had been installed after the survey by Bolan and Urso Ltd. Water levels were measured precisely relative to the top of the well casings with electric tapes calibrated to 1 cm intervals. These levels were used with the reference elevation of the casing to calculate water elevations for each monitoring well. Water level, reference elevation and water elevation data are included in Appendix 5.

3.2.4 Groundwater Sampling

Analytical Approach

As described in Chapter 2.0, there is a long list of constituents of potential environmental concern which may occur in the groundwater beneath the Algoma slag site and which may be migrating off-site. A rationale for developing a short list of chemical constituents to be analyzed was adopted. The basic approach was to select one of three levels of analysis as follows:

- Level 1 - screening or surrogate parameters used as indicators of other constituents
- Level 2 - key chemical parameters and targetted constituents which represent the most significant concerns for the various samples collected

- Level 3 - the full suite of chemical parameters outlined in the MOE Request for Proposal. This analysis was applied to only a few select samples to confirm that Level 2 analysis covered the significant contaminants in the system.

Four sampling rounds were completed during this investigation. Samples were collected every three months to provide seasonal information. The sampling and analytical scheme was revised after the results of the initial round (Summer 1988) were evaluated. Revisions to both the number and types of parameters for each analytical level and the number of each type of sample were made relative to the original work plan (see BEAK Proposal, 1988). The parameters included in the Level 2 analyses were revised to emphasize the collection of samples for analyses of key constituents identified during the initial round of sampling. During the last three sampling rounds, the number of Level 3 analyses were reduced from that originally planned (BEAK Proposal, 1988) to allow more Level 2 analyses to be conducted.

BEAK and the MOE developed the following objectives for groundwater chemical data collection during the course of this study:

- Each site-perimeter well would have at least two samples collected for metals, PAH and total cyanide analyses and one sample for nutrients (TKN and total phosphorous) analyses to support the off-site mass flux calculations.
- Detailed chemical characterization (Level 3 analyses) of samples from three wells (A7-1, C4, D3-2) would be conducted for each sampling round to determine the temporal nature of groundwater chemistry. These three wells were selected for Level 3 analyses for continuity with the initial sampling round (Summer 1988).

During the initial round of sampling (Summer 1988), higher level analyses were conducted for samples collected from monitoring wells located in suspected source areas to enable full

chemical characterization of the constituents most likely to be migrating from the site. Monitoring wells located around the site perimeter generally were sampled for lower level analyses. This emphasis changed for subsequent sampling events. Wells adjacent to the St. Marys River shoreline and the on-site creeks were generally sampled for higher level analyses to allow calculation of the flux of dissolved constituent leaving the site. Less sampling emphasis was placed on wells within the site interior near suspected source areas. The fourth and final round of sampling (Spring 1989) was conducted to fill remaining data gaps. Table 3.1 provides a schedule of the level of analyses conducted for each sampling event. Table 3.2 lists the chemical parameters included in each analytical level.

Sampling Methods

Groundwater samples were collected following a period during which the wells were developed by pumping to reduce the silt content and enhance the performance of the well screen. A minimum of three casing volumes were removed from each well prior to sample collection to ensure fresh groundwater samples were retrieved. Samples were collected from each of the wells, except A7-1, using dedicated Waterra hand pumps. Samples from well A7-1 were collected using a bottom-loading and bottom-emptying teflon bailer because construction of the well (depth and large diameter casing) did not facilitate the use nor storage of a Waterra system.

Quality Assurance and Control Samples

Replicate samples were collected from approximately 5% of the wells. These samples were collected within 2 to 5 minutes of the original samples. Trip blanks consisting of sample containers filled with deionized water in the laboratory comprised 5% of the samples. These were opened on-site, the appropriate preservatives added and recapped. The trip blanks were stored, shipped and analyzed with the regular samples. Table 3.1 provides a summary of the number of replicate and trip blank samples and their level of analyses for each sampling event.

Samples for Tritium Analyses

One-litre groundwater samples were collected from seven deep monitoring wells (A4-1, A7-1, B2-1, B2-3, B4-1, D3-1, D5-1) for enriched analysis of tritium. Samples were analyzed at the Environmental Isotope Laboratory, University of Waterloo using a special technique (enrichment) which allows values as low as 0.10 tritium unit (TU) to be measured.

3.2.5 Creek Bed Mini-Piezometers

Mini-piezometer transects were installed in three locations: Locations A and B in the West Davignon Diversion and Location C in the Baseline Road ditch. Figure 3.1 shows the locations of these transects. Each transect consists of four to seven mini-piezometers in nests of two or three. The nests were installed in a line across the creek. The mini-piezometers consist of a stainless steel drive point/monitoring well tip (0.26 m long by 1.27 I.D.) connected to 0.95 cm I.D. polyethylene tubing extending to the surface and protected by 1.27 cm I.D. black steel pipe.

Installation of the mini-piezometers was performed by one of two methods. Where the subsurface permitted, the monitoring wells were installed with a vibrating hammer. Where installation of the monitoring wells by this method was impeded by a rocky subsurface, trenches were dug down to the desired depth by a backhoe and the monitoring well tip was pushed 30 to 50 cm (where possible) into the undisturbed underlying sediments. The total depth to which the centre of each monitoring well screen was placed is listed in Table 3.3.

Hydraulic heads, relative to the stream bed, were measured using a manometer. Details of the construction and application of this device are given in Lee and Cherry (1978). Briefly, a tube was connected to the mini-piezometer and to the creek water surface. Vacuum was exerted on this tube and the difference in creek water and groundwater levels in the tube was recorded. This device could not be used satisfactorily at all mini-piezometers because of the

suspected presence of low hydraulic conductivity materials which impeded the flow of sufficient water volume into the manometer for successful operation. In such cases, the depth to water within the mini-piezometer was measured by sounding the water surface with a length of small diameter plastic tubing. The top of one mini-piezometer and the creek water elevation were surveyed by BEAK personnel at each mini-piezometer transect location to facilitate preparation of cross-sections. The elevation and hydraulic head data are provided in Tables 3.3 and 3.4 respectively

Selected mini-piezometers were sampled during the Spring 1989 groundwater sampling event. The mini-piezometers were first developed by removing up to one litre of water by pumping with a vacuum flask. The mini-piezometer tubing was fitted to the stopper of a vacuum flask which was then evacuated by vacuum hand pump. The volume removed from the mini-piezometer depended upon its ability to yield water. Table 3.5 provides the volume of water removed from each mini-piezometer for development. Selected mini-piezometers were sampled immediately following development. The criteria for selection of mini-piezometers for sampling were:

- the mini-piezometer was capable of yielding sufficient water volume for analysis (at least 100 ml) in a timely manner, and
- the deepest mini-piezometer at a nest was most preferable for sampling.

The plan was to sample nine mini-piezometers for Level 2 plus BTX and PAH analyses (see Table 3.1); however low sample volumes collected from the mini-piezometers prevented implementation of this plan. Instead, 11 mini-piezometers were sampled for the parameters listed in Table 3.5.

3.3 Geology

Geologic data were obtained from borehole logs for previous investigations of the site (Geocon, 1983; GLL, 1988; and CRA, 1988) and combined with the information illustrated on the borehole logs for this investigation (Appendix 2). The borehole logs were used to determine the elevations of geologic unit contacts and thicknesses. This information, compiled in data base format in Appendix 8, was used to determine the subsurface geology of the Algoma slag site.

3.3.1 Regional Geology

The regional geology of the Algoma slag site and surrounding area is illustrated, schematically in Figure 3.2 (Geocon, 1983). The Algoma slag site is underlain by a sequence of unconsolidated glacial fluvial, glaciolacustrine and glacial till granular deposits. Bedrock is Cambrian sandstone and has extremely irregular topography beneath the site. The sediments and sandstone pinch out against the Precambrian basement rock which outcrops in the highlands to the north of Sault Ste. Marie. Bedrock occurs at a shallow depth beneath the topographically high slag area (near the middle of the site), but drops off quickly to the north and east, and more gradually to the southwest.

3.3.2 Site Geology

Figure 3.3 illustrates the general stratigraphic sequence below the Algoma slag site. Two overburden regimes are indicated on this figure: a glacial till regime for the west side of the site and a glaciolacustrine regime for the east. These regimes are characterized by markedly different overburden types which are the result of different depositional environments. The top unit is slag fill. Below this the geologic units are:

-
- shallow sand
 - laminated clay and silt
 - basal sand and gravel
 - bedrock

Below the shallow sand on the east part of the site, the geologic units from shallow to deep are:

- shallow silty sand
- silty sand till
- bedrock

Figures 3.4 and 3.5 are cross-sections illustrating the detailed subsurface geology of the Algoma slag site. The locations of the cross-sections are shown on Figure 3.1. A brief description of the geologic units is given below; a more detailed description is given on the borehole logs in Appendix 2.

Bedrock

Bedrock is comprised of a dense red and white feldspathic sandstone of Cambrian age. The upper metre of this sandstone is brittle and highly fractured as a result of weathering during pre-glacial exposure. Figure 3.6 shows the topography of the bedrock surface beneath the site. A bedrock ridge is located beneath the western part of the site near wells C2 and D6. This bedrock ridge, also shown on the geologic cross-sections (Figures 3.4 and 3.5), seems to have controlled deposition of subsequent geologic units as most overlying units thicken away from this ridge. A bedrock trough is located beneath the eastern part of the site. This trough trends northwest to southeast near wells A7 and B4.

Basal Sand and Gravel

A clean, coarse sand and gravel overlies the weathered bedrock surface in the eastern area of the site (Figures 3.4 and 3.5). This sand and gravel is multi-coloured, semi-rounded, and is overlain by a fine- to coarse-grained brown sand and gravel. The basal sand and gravel unit thickens to the east, away from the bedrock ridge and is up to 19 m thick below the site.

Laminated Clay and Silt

A thick unit comprised of laminated cohesive red clay and brown silt lies above the basal sand and gravel unit. The laminations are indicative of a lacustrine depositional origin. The thickness of this unit is shown on Figure 3.7. This unit also thickens to the east to a maximum of 37 m away from the bedrock ridge. The top of this unit generally slopes to the northeast.

Silty Sand Till

A silty sand till overlies bedrock below the western part of the site. This dense, red, pebbly to stony, silty sand till thickens toward the southwest. A red silty sand unit flanks the eastern side of the bedrock high but it is less till-like than the unit to the west. The eastern silty sand thickens away from the high and may be hydraulically reworked till and is also referred to as "silty sand till".

Shallow Sand/Shallow Silty Sand

A sand unit up to 9 m thick overlies the laminated clay and silt in the east and the silty sand till in the west. This sand unit generally thickens away from the bedrock ridge. The shallow sand is siltier below the western part of the site (shallow silty sand) than it is below the eastern part (shallow sand). The sand is fairly well sorted and contains some gravel below

the eastern part of the site. It appears fluvial and may have been deposited by Spring or Bennett Creeks prior to construction of the diversion channels. The upper 2 m contains a discontinuous black, organic-rich silt (beneath the eastern part of the site). In some areas, the silt unit is actually a peat. The shallow silty sand is poorly-sorted and subsequently contains more silt below the western part of the site. This sand may also have a fluvial origin. The change from well- to poorly-sorted appears to coincide with the edge of the laminated clay and silt (see Figures 3.4 and 3.5). Where underlain by laminated clay and silt (eastern part of site), the sand is well-sorted. The sand in this area is referred to as "shallow sand". Where underlain by silty sand till, the sand is poorly-sorted and is referred to as "shallow silty sand".

Slag Fill

The uppermost unit is generally comprised of slag material which varies in grain size from very large boulders to very coarse sand. The finer component is generally located at the base of the slag deposit. Sand and gravel fill, and coal and coke fines were found at some drilling locations. The slag fill thickness varies from 0 at well D5 along the shoreline of the St. Marys River to 14.6 m at Geocon well 11 located in the topographically high central to western part of the site.

3.3.3 Original Site Topography

Figure 3.8 illustrates the ground surface topography prior to the disposal of slag and shoreline infilling. The former ground surface had a relief of about 8 m. A former topographic high was located in the vicinity of monitoring wells C3 and 11 below the central western part of the site. The location of this high corresponds with the location of the bedrock high shown on Figure 3.6. The topography of the original ground surface is an important control of the groundwater flow direction (see Section 3.5). Historical airphotos of the site show the former shoreline to be located at approximately the 182 m above mean sea level topographic contour on Figure 3.8.

3.4 Hydrostratigraphy

The geologic units present below the Algoma slag site were divided into hydrostratigraphic units according to their water-bearing properties. Permeable materials which have a significant capacity to transmit water are called aquifers, whereas materials with low permeability which have a low capacity to transmit water are called aquitards.

3.4.1 Hydrostratigraphic Units

The geologic units described in Section 3.2 are divided into the following major hydrostratigraphic units:

- Unconfined (or Watertable) Aquifer - This unit is present beneath the entire slag site and is comprised of the slag fill. Beneath the eastern half of the site, it is also comprised of shallow sand. The organic silt located at the top of the shallow sand is thought to be a semi-confining layer between the slag fill material and underlying shallow sand near the former Domtar facility in the eastern part of the site (CRA, 1988). For the purposes here, the slag fill, organic silt and shallow sand comprise the unconfined aquifer and are not further subdivided.
- Aquitard - Below the eastern part of the site, the laminated clay and silt unit hydraulically separates the unconfined aquifer from the underlying permeable basal sand and gravel, and bedrock units. The shallow silty sand and silty sand till comprise the aquitard beneath the western part of the site.
- Confined Aquifer - The basal sand and gravel, and the bedrock comprise the confined aquifer. This unit serves as a regional, high-capacity water resource.

3.4.2 Hydraulic Conductivity

The movement of water through the subsurface material is dependent on the water-bearing capacity or hydraulic conductivity of the subsurface material. Hydraulic conductivity was determined by field testing during this and previous investigations.

Hydraulic Conductivity Test Results

Single well hydraulic conductivity tests were conducted on most wells installed during this investigation to determine the hydraulic conductivity of the different materials encountered during drilling. Plots of well response versus time were prepared for each test to facilitate calculation of hydraulic conductivity values. The test data and response plots are located in Appendix 3. Appendix 1 provides a detailed discussion of the preparation and use of the well response plots.

The well response plots for this investigation generally fall into one of three categories:

- "Decreasing rate responses" occurred for the monitoring wells installed in the siltier geologic units (for example, the organic silt, shallow silty sand and silty sand till). The plots for these tests are characterized by a steep initial curve representing rapid water level recovery in the field, followed by progressive flattening of the curve indicating progressive decrease in the rate of water level recovery. The response plots for wells A1-2 and A1-1 are examples of this type of plot (see Appendix 3). The decreasing rate of recovery could be the result of siltation of the well screen, sand pack or fractures in the geologic material. This data was analysed by fitting two lines to the data - one to the initial part of the curve, and one to the later part of the curve. For each test, two hydraulic conductivities are reported which generally differ by about a factor of 3.

- "Bilinear responses" were characterized by a quick water level recovery followed suddenly by a slower recovery. These responses generally occurred for tests in which the sand pack was dewatered during the response test (i.e. water level in the well was lower than the top of the sand pack during the initial part of the test). The plots are characterized by a steep initial line followed by a less steep line. The break in slope corresponds to the point during the test where water in the well was at the elevation of the top of the sand. The data for tests at A2-2 and A6 show this type of response. Hydraulic conductivities were calculated for each response; however, the hydraulic conductivity for the initial response is not representative of the aquifer conditions because it is affected by dewatering of the sand pack and is not appropriate for the analysis method used.
- "Constant responses" occurred for most remaining cases when the water levels in the monitoring wells were not lowered below the tops of the sand packs. The plots for these tests are linear. Test results for wells A4-1 and B2-2 are examples of this type of response.

The hydraulic conductivity data obtained for this investigation were compiled with those from previous studies of the site according to geologic unit. This data compilation is located in Appendix 3. All hydraulic conductivity data are included in this compilation with the following exceptions:

- Hydraulic conductivity values calculated from both early and late responses are included in the compilation for wells having decreasing rate responses. If only two data points fell along the line used to calculate hydraulic conductivity, then this value was not used in the compilation because insufficient data supports it.
- Hydraulic conductivity values calculated from early results for bilinear responses were not used in the compilation because these results were affected by

dewatering the well sand pack and are, therefore, not representative of aquifer conditions. Only the hydraulic conductivity values calculated from late results were used in the data compilation.

The compilation of all hydraulic conductivity data provides a more detailed characterization of the subsurface and allows calculation of average values for each unit with more confidence. The range of hydraulic conductivity and average of the log transformed hydraulic conductivity value summarized in Table 3.6 for each geologic unit are consistent with typical values for these types of materials (Freeze and Cherry, 1979). Generally, the range of hydraulic conductivities for each unit spans about two orders of magnitude. However, the shallow silty sand (below the west part of the site), silty sand till and bedrock units exhibit more variability -- the hydraulic conductivities for the shallow silty sand and silty sand till vary by over three orders of magnitude while the bedrock unit varies by over four orders of magnitude. This variability is likely due to the heterogeneous grain size distribution of the shallow silty sand and silty sand till units and the irregular spacing of fractures in the bedrock.

Unconfined Aquifer

The hydraulic conductivities of the units comprising the unconfined aquifer (see Table 3.6) range from an average of 4.8×10^{-6} m/s for the organic silt to 8.7×10^{-5} m/s for the shallow sand unit. The organic silt has an average hydraulic conductivity about an order of magnitude lower than the shallow sand and slag fill. The report by CRA (1988) indicates perched water over the organic silt and downward gradients across this unit which suggest the layer is semi-confining. The hydraulic conductivity contrast between the silt and sand supports this interpretation.

Aquitard

The hydraulic conductivity of the units comprising the aquitard range from an average of 3.0×10^{-8} m/s for the laminated clay and silt to 1.9×10^{-6} m/s for the shallow silty sand. This range of hydraulic conductivities is one to three orders of magnitude lower than the range of average hydraulic conductivities for the unconfined aquifer.

Confined Aquifer

The average hydraulic conductivity of the units comprising the confined aquifer are 1.7×10^{-6} m/s for bedrock and 1.6×10^{-4} m/s for the basal sand and gravel. Because of the smaller number of measurements and the fractured nature of the material, the average hydraulic conductivity value reported for bedrock may not be representative. Groundwater in the bedrock would tend to flow along fractures because intercrystalline or intergranular pore spaces are likely to be negligible. Representative hydraulic conductivity testing of this unit would not occur unless the monitoring well tested intersected such fractures in the bedrock. Nonetheless, the average hydraulic conductivity value reported here is consistent with typical hydraulic conductivities for fractured rock presented in Freeze and Cherry (1979).

3.5 Groundwater Flow Conditions

Groundwater flow occurs through the pore spaces of porous granular materials, and occurs predominantly through fractures in less permeable rock material. Groundwater flow is dependent upon the hydraulic gradient (or driving force) and the hydraulic conductivity (or resistance to flow) of the geologic material through which the flow occurs.

3.5.1 Regional Groundwater Flow Conditions

Regional groundwater flow is from the north toward the St. Marys River in the south (Geocon, 1983). Regional recharge to the bedrock and basal granular aquifer likely occurs in the highland area to the north of Sault Ste. Marie (see Figure 3.2). The major zone of regional groundwater discharge is the St. Marys River.

3.5.2 Site Watertable Configuration

Watertable elevation data from wells installed for this investigation and existing wells which could be located were used to prepare a watertable contour map (Figure 3.9).

The configuration of the watertable beneath the Algoma slag site is generally controlled by the relief of the original ground surface (compare with Figure 3.8) and the location of the on-site creeks. A watertable mound is located near wells C3, 9 and 11 (Figure 3.9), coincident with the location of the former topographic high (Figure 3.8). Shallow groundwater flow occurs radially outwards from this mound to the St. Marys River, West Davignon Diversion and the Baseline Road ditch. Below the eastern half of the site, the watertable slopes gradually in a southeastern direction toward St. Marys River. The slope of the watertable beneath the northeast site area is also toward the south and southeast. The slope of the watertable is similar to the original ground surface elevation contours to the original shoreline in this area. The watertable is 0.5 to 2 m above the original ground surface north of the former shoreline.

3.5.3 Water Level Temporal Trends

Monthly water level data and hydrographs contained in Appendix 5 indicate the highest water elevations during the monitoring period occurred in November 1988. The lowest water elevations generally occurred in March 1989 but some wells also exhibit low water levels for

October 1988. The seasonal trends likely indicate the amount of precipitation recharge to the subsurface - large volumes of rainfall infiltration cause high water levels in the fall while the low water levels in March are due to the absence of significant amounts of infiltration during the winter. The approximate average water elevation change measured over the one-year monitoring period was ± 0.5 m.

3.5.4 Shallow Horizontal Gradients

Horizontal gradients, which determine the rate and direction of lateral groundwater flow, were calculated using the monthly water level data and distances between wells (adjusted to give distances perpendicular to watertables elevation contours on Figure 3.9). The range of, and average, horizontal hydraulic gradients are listed in Table 3.7. The hydraulic gradient associated with the watertable mound was fairly steep (0.004 to 0.01). The gradient beneath the eastern part of the site was less steep (0.003 to 0.004). The hydraulic gradients generally remained constant with time during the one-year monitoring period.

3.5.5 Vertical Hydraulic Gradients

Table 3.8 summarizes the vertical hydraulic gradients at nested monitoring well locations on-site. Upward vertical gradients predominate at all locations (except A1 and Geocon nests 9 and 1) indicating groundwater discharge conditions. The upward hydraulic gradients vary from about 3.0×10^{-3} to 1.3×10^{-1} . Some well nests showing predominantly upward gradients also show occasional downward gradients (nests A4, A7, and D3; see Table 3.8). The occasional downward gradients may be due to short-term recharge effects or the effect of St. Marys River water level fluctuations, both which may influence the watertable elevations and cause apparent gradient reversals.

Downward vertical gradients were measured at well nest A1 (-2.8×10^{-3} to -2.4×10^{-2}), Geocon 1 (-3.8×10^{-2}) and Geocon 9 (-6.6×10^{-3}) indicating recharge conditions. Monitoring well nests

A1 and Geocon 9 are situated near the oil pond and the pickling liquor disposal area, in a valley infilled with permeable slag material. Large volumes of waste pickling liquor (38,000 L/d) and oily water (280,000 L/month) are disposed here, and thus this area constitutes a local groundwater recharge zone. The downward gradients are consistent with this recharge. Geocon well nest 1, located in a low area at the base of the slag escarpment near the mouth of the West Davignon Diversion, was surrounded by surface water at the time of water level measurement. The downward gradient present at this well nest is likely due to the infiltration of the ponded water in this wet area.

Figures 3.10 and 3.11 show the direction of groundwater flow in cross-section. The flow directions shown on these figures have been determined using hydraulic gradient data, the results of tritium analyses and chemical data which are described in subsequent sections. These cross-sections show the predominantly downward flow direction near the oil pond and the upward flow direction at the West Davignon Diversion and St. Marys River.

3.5.6 Creek Bed Mini-Piezometer Studies

Local discharge zones in the slag disposal area appear to include:

- the Baseline Road ditch and Spring Creek, which receive shallow groundwater flow from the watertable mound beneath the western part of the site and from the gently sloping slag fill area to the north;
- Bennett Creek which drains the eastern part of the slag fill area north of Baseline Road;
- the West Davignon Diversion which receives recharge from the western face of the slag pile; and

- the St. Marys River, which drains the southern face of the site and the area to the south of Spring Creek.

As identified above, four on-site (or peripheral to the site) creeks (West Davignon Diversion, Baseline Road ditch, Bennett Creek and Spring Creek) have the potential to receive groundwater discharging from the subsurface. Spring and Bennett Creeks were extensively studied during previous investigations (CRA, 1988; GLL, 1988) so this study focused on the West Davignon Diversion and Baseline Road ditch.

Reconnaissance of the West Davignon Diversion and Baseline Road ditch in the summer of 1988 indicated several areas of groundwater seepage to the streams. The east bank of the West Davignon Diversion was notably oily and several areas of oily water seepage were apparent approximately 0 to 0.5 m above the creek water level. The Baseline Road ditch contained milky white water. Some areas of milky white groundwater seepage were apparent along the south side of the road at the base of the slag escarpment.

The potential for groundwater seepage from the slag pile into the West Davignon Diversion and Baseline Road ditch was investigated further through the use of mini-piezometers. Mini-piezometers are similar to the monitoring wells installed on-site, but they are smaller and installed manually. Their use in investigations of groundwater-surface water interactions is well documented (Lee and Cherry, 1978). The objective of the creek bed mini-piezometer study was to determine if shallow groundwater from the slag site was indeed discharging to the on-site surface drainage.

Instrumentation

Two locations at the West Davignon Creek (Transects A and B on Figure 3.1) and one at the Baseline Road ditch (Transect C on Figure 3.1) were identified for installation of mini-piezometers. Site A was located adjacent to monitoring well D6 in an area of visible

oily water seepage. Five mini-piezometers were installed (three shallow and two deep) in three nests. Site B is located half-way between Site A and the St. Marys River also in an area of visible oily seepage. Six mini-piezometers (four shallow and two deep) in two nests were installed at Site B. Site C was located towards the eastern end of Baseline Road ditch in an area of visible seepage from the south side. A total of seven mini-piezometers (three shallow and four deep) were installed across the Baseline Road ditch. The total depths of the mini-piezometers are listed in Table 3.3 while Figures 3.12 through 3.14 show their relative locations.

Excavation of the West Davignon Diversion during mini-piezometer installation revealed a 30 cm thick boulder rip-rap overlying a 15 cm layer of Grade B gravel (slag). These materials were used in the construction of the creek diversion channel. The underlying sediments were a pink to reddish-brown boulder sandy till with some discontinuous clayey silt layers (silty sand till unit). Bedrock (sandstone), encountered at 1.5 to 2.5 metre beneath the ground surface, prevented the installation of mini-piezometers at depths greater than this.

No boulders were encountered at the Baseline Road transect (Site C). All monitoring wells were installed through surface water ponding on the former road and in the adjacent ditches. A soft, white, very fine-grained sediment was encountered in the bottoms of the ditches.

Shallow Groundwater Flow Directions

Water levels in the mini-piezometers were measured twice (Fall 1988 and Spring 1989) during this study. The measurements for Fall 1988 were obtained using a manometer as described in Sub-section 3.2.5. Difficulty obtaining reliable readings with this device resulted in modification of the measurement method. Subsequently, the water level measurements for Spring 1989 were obtained by sounding the water surface in the mini-piezometer and by the manometer, where practical. Water level data are presented in Table 3.4.

Vertical gradients at creek bed mini-piezometer nests were calculated from water level data (Table 3.4) and mini-piezometer depths (Table 3.3) and are presented in Table 3.9. Vertical gradients across the interval between the shallowest mini-piezometer in a nest and the creek bottom are also presented for mini-piezometers installed through surface water.

Upward directed vertical gradients were measured at all three creek bed sites in the Fall 1988. The gradients ranged from 0.26 for Transect B to greater than 1.9 for Transect A. These gradients are one to two orders of magnitude greater than the vertical gradients at monitoring well nests. The high vertical gradients demonstrate that the Baseline Road ditch and West Davignon Diversion were groundwater discharge zones during the fall.

Vertical gradients were predominantly strongly downward during the Spring 1989 monitoring event. The downward gradients ranged from -0.89 at Site A, -0.08 to -1.20 at Site B, and -0.09 to -1.09 at Site C. The downward gradients are likely due to the infiltration of precipitation and melt water which typically occurs in the spring. Upward gradients of 0.06 and 0.24 were measured in the shallow subsurface at Sites A and C, respectively. Although downward gradients predominate in the spring locally, the water level data, as described below, indicate that groundwater discharge continues in the West Davignon Diversion.

Figures 3.12 through 3.14 illustrate shallow groundwater flow conditions at the mini-piezometer transects. The cross-sections were prepared using water level data from Spring 1989. Figures 3.12 and 3.13 (Locations A and B in West Davignon Diversion respectively) show the watertable below the east bank intersecting the channel approximately 0.5 m above the creek water surface. The location of this intersection results in a seepage face between the watertable and creek water surface which is consistent with observations of seepage along this bank. Hydraulic gradients below the east bank tend to be steeper than below the west bank which suggests that most of the groundwater discharge to the West Davignon Diversion would be from the east bank where water is contributed by the slag pile.

Groundwater flow directions in the vicinity of Baseline Road ditch are illustrated on Figure 3.14. Water from the ditch appears to be moving into the shallow subsurface. This direction is contrary to that expected of a groundwater discharge zone and is likely the result of significant volumes of spring runoff in the ditch which caused an excess hydraulic head relative to the groundwater. This water appears to be drained through a lower hydraulic head zone approximately 2 m below the bottom of the ditch. The Baseline Road ditch appears to be a groundwater recharge zone in the spring; however, discharge to this creek was evident in the fall.

3.5.7 Deep Groundwater Flow Conditions

The confined basal sand and gravel and bedrock aquifer is utilized for water supply by the City of Sault Ste. Marie. The locations of existing water supply wells are shown on Figure 1.2. Some concern has been expressed that groundwater from the Algoma slag site may migrate toward these wells and affect groundwater quality. Although regional groundwater flow is south toward the St. Marys River, the presence of a watertable mound beneath the site has caused concern because of the potential for this mound to induce the movement of site-affected groundwater toward the city wells. This subsection describes the results of monitoring undertaken to address this concern.

Data specifically to assess the direction and rate of groundwater flow in the confined aquifer were collected during the following activities:

- collection of monthly water level data from monitoring wells installed in the confined aquifer during this investigation during the course of this study;
- collection of a set of water level data during the spring of 1989 from Geocon monitoring wells and the Domtar water supply well installed in the confined aquifer to supplement the monthly water level data;

- collection of hourly water level data from two deep monitoring wells (A7-1 and A4-1) and the Domtar water supply well from 06 June to 07 July 1989; and
- analysis of groundwater samples for tritium.

The results of these activities are discussed below.

Water Level Data for Existing Deep Wells

Figure 3.15 is a contour map of the basal sand and gravel and bedrock potentiometric surface. Water elevations for monitoring wells installed near the base of the silty sand till are shown in parentheses on the figure. Although the parenthetical data are not strictly for the confined aquifer, they are for the deep aquitard and are likely to be fairly representative of the water elevation in the confined aquifer. The western limit of the laminated clay is shown on the figure for reference. The pattern of the equipotential contours on Figure 3.15 is similar to the pattern exhibited by the watertable elevation contours (Figure 3.9). Groundwater flow in the confined aquifer is directed radially outward from the piezometric high near wells C3, 9 and A1. East of this high, groundwater flow is directed south toward the St. Marys River. The shape of the confined aquifer potentiometric surface does not suggest that groundwater in the confined aquifer would move off-site toward the city water supply wells to the north.

Monthly Water Level Data

Four monitoring wells (A4-1, A7-1, B2-1, B2-3) were installed into the confined aquifer (basal sand and gravel or bedrock) for this investigation. Water levels were measured at these monitoring wells at approximately monthly intervals. Figure 3.16 is a hydrograph illustrating the water level trends during the study period.

Water elevations at wells B2-1, B2-3 and A4-1 tend to show seasonal variation consistent with the watertable trends (see subsection 3.5.3) with the highest water levels occurring in the fall

(November 1988) and lowest in the spring (March 1989). The groundwater elevation at well A7-1 located at the northern boundary of the site shows the greatest variability (elevations change by about 1.5 m). The groundwater elevations at other confined aquifer wells show less variation (elevation changes of about 0.7 to 1.3 m). The water elevation at A7-1 was always higher than at the other confined aquifer wells (Figure 3.16) indicating that hydraulic gradients were consistently directed toward the south. The consistency in gradient direction suggests groundwater flow in the confined aquifer to also be consistently directed toward the south during this investigation.

Hourly Water Level Data

Water levels were monitored hourly at monitoring wells A7-1 and A4-1, and the inactive water supply well on the former Domtar facility (referred to as the "Domtar well") during the period 06 June to 07 July 1989. Water levels were measured using pressure transducers and data loggers supplied and installed by the Water Resources Branch of the Ontario Ministry of the Environment. These measurements were obtained to determine whether short-term water level fluctuations could cause a reversal in the hydraulic gradient direction resulting in the movement of groundwater off-site toward the city water supply wells. In particular, pumping of the city water supply wells to the north of the site was thought to potentially exacerbate the gradient reversal.

Figure 3.17 is a hydrograph illustrating the water elevation trends for the three wells for which hourly data were collected. Water elevations at A7-1 show the most fluctuation. The Domtar well shows a similar pattern of fluctuation, but the amplitude of the fluctuations is dampened compared to A7-1. The water elevation at well A4-1 shows very little fluctuation during the monitoring period. The water level fluctuations at A7-1 and the Domtar well are likely due to pumping at the city water supply wells located to the north of the site (see Figure 1.2). Regardless of these fluctuations, the hydraulic gradient remained consistently directed toward the south during the monitoring period. There is no evidence to suggest that groundwater in the confined aquifer would flow from the site toward the city water supply wells.

Tritium Analyses

Tritium (^3H) is a radioactive isotope of hydrogen that occurs naturally in water by incorporation into the water molecule. Large quantities of tritium were introduced to the hydrologic cycle from 1953 to 1962 as a result of large-scale atmospheric testing of thermonuclear bombs. Prior to 1952, it is estimated that the natural tritium content of precipitation was in the range of about 5 to 20 TU (1 Tritium Unit or TU is equal to 1 tritium atom in 10^{18} hydrogen atoms). Groundwater that was recharged from rain or snowmelt prior to 1953 is expected to have tritium concentrations below about 2 to 4 TU since the half-life of tritium is 12.3 years. By measuring the tritium content of groundwater samples, it may be possible to distinguish between post-1953 "modern" water and "pre-bomb" water. If samples contain no detectable tritium, it is reasonable to conclude that significant amounts of modern water are not present or that the groundwater entered the subsurface prior to 1953. Tritium analyses are often used in groundwater flow investigations to distinguish different age zones within the groundwater flow regime. Groundwater samples for tritium analyses were collected from selected deep monitoring wells to assist in the interpretation of the deep flow conditions.

Groundwater samples were collected from five wells (A4-1, B4-1, B2-3, D3-1 and D5-1) during the Winter 1988 sampling event for analysis of tritium concentrations. Ice within well A7-1, also scheduled for sample collection, prevented sample collection from this location. Groundwater samples were collected from three monitoring wells (B2-1, A7-1, B2-3) during the Spring 1989 sampling event for tritium analysis. A sample was also collected from well D3-1 during this event, however, this sample was destroyed during shipment from the site. The results of the tritium analyses are provided in Table 3.10.

Samples from wells B2-1, A7-1, B2-3 and D5-1 contained tritium at appreciable concentrations (24.2 to 68.3 TU) while samples from D3-1, A4-1, and B4-1 contained considerably less tritium (0.8, 1.2 and 4.9 TU respectively). The high concentrations of tritium are indicative of post-1953 water. Wells B2-3 and A7-1 were drilled using the wet

rotary method which introduced water from the public distribution system to the subsurface. Water from the distribution system was also added during drilling to prevent sand from jamming the auger head at B2-1 and D5-1. Although every attempt was made to remove this water immediately following drilling, it is likely that some of this water remained in the subsurface and was consequently sampled.

The low concentrations of tritium occurring in samples from wells A4-1, B4-1 and D3-1 indicate that the deep system was recharged prior to the 1950's at these locations. The confined aquifer is overlain by the laminated clay and silt aquitard at A4-1 and B4-1. It would appear that the aquitard effectively separates the overlying unconfined aquifer from the confined aquifer at these locations. Furthermore, the effectiveness of this barrier at locations B4-1 and A4-1 and the presence of upward gradients along the shoreline which would prevent shallow water from moving down to the deeper system support the suggestion that water samples collected from B2-1, B2-3 and A7-1 were affected by drilling fluids. The deep system at well D3-1, which screened in the silty sand till approximately 19 m below ground surface (15 m below the slag fill), also appears to have been recharged prior to the 1950's and is consistent with the idea that the St. Marys River is a regional discharge area for the confined aquifer.

Groundwater flow directions and tritium data are shown on Figures 3.10, 3.11, 3.18 and 3.19. The locations of the cross-sections are shown on Figures 3.1 and 3.15. The tritium data indicate that, although flow is downward near wells 9 and A1, this groundwater has not migrated considerably through the deep system. Upward gradients appear to prevent significant downward movement of the shallow groundwater.

Summary of Deep Groundwater Flow

The hourly and monthly water level data collected during this investigation indicate that hydraulic gradients in the confined aquifer are directed toward the south. No evidence of gradient reversal was found, indicating that the groundwater in the confined aquifer does not

migrate from beneath the Algoma slag site toward the city water supply wells. The gradients and tritium data indicate that even though well A4-1 is located relatively close to (just north of) the slag pile, contamination of the confined aquifer at that location is not expected. The chemical data (discussed later in Section 3.6) also support this interpretation because groundwater samples from A4-1 were not affected by the constituents from the shallow subsurface or surface. The aquitard overlying the confined aquifer appears to have effectively separated the shallow, relatively young groundwater system from the older deeper system. These data, coupled with the presence of persistent upward gradients suggest that the city water supply wells will not be affected by dissolved constituents in the shallow groundwater beneath the Algoma slag site under current pumping conditions. Monitoring of water levels can be conducted in the future to confirm these flow conditions on an ongoing basis.

3.5.8 Estimated Groundwater Fluxes

The main purpose of the hydrogeologic study was to determine the flux of dissolved constituents leaving the Algoma slag site. To do so, it was necessary to first determine the off-site flux of groundwater.

Calculation Method

The groundwater flux has been calculated using the Darcy equation:

$$Q=kiA$$

where: Q = groundwater flux per unit cross-sectional area (L^3/T),
 k = horizontal hydraulic conductivity (L/T),
 i = horizontal hydraulic gradient (L/L), and
 A = cross-sectional area (L^2).

For the above equation, the unit types are shown in parentheses with L and T referring to units of length and time respectively.

Only groundwater discharge from the unconfined aquifer is estimated because most dissolved constituents are found in this unit (see Section 3.6). The confined aquifer is relatively unaffected by disposal of materials and by-products at the Algoma slag site. Groundwater flux through the aquitard is not considered important because the aquitard is one to four orders of magnitude less permeable than the unconfined aquifer, thus the groundwater flux through this unit is negligible when compared to the flux through the unconfined aquifer. Flux through the aquitard is only considered where the watertable is located below the bottom of the unconfined aquifer. The values used for input to the Darcy equation are described below. Detailed calculations of flux are provided in Appendix 9 and are summarized in Table 3.11.

The Algoma slag site was partitioned into six elements, as indicated in Figure 3.20 to estimate the shallow groundwater flux from the site to the various local discharge areas. The boundaries of the elements were based on areas having fairly uniform flow directions (Figure 3.9) and average horizontal hydraulic gradients. The flux boundaries were established perpendicular to the flow direction.

The average and range of hydraulic conductivity values in Table 3.6 for the slag fill and shallow sand (eastern site) and the average and range of hydraulic gradients calculated from well pairs within the element of interest were used to calculate the average and range of groundwater fluxes. Cross-sectional area is equal to the length of the element perimeter times the thickness of the unit through which flow occurs. Element perimeter lengths were measured directly from Figure 3.20. The thickness of the shallow sand was obtained by averaging the thickness of sand at wells along the element perimeter. The slag unit was not entirely saturated, so the thickness of this unit was obtained by determining the average and range of saturated thicknesses at wells around the element perimeter. These thicknesses were then used to calculate the average and range of groundwater flux.

Groundwater Flux

Discharge zones for groundwater below the Algoma slag site are the St. Marys River, West Davignon Diversion, Bennett Creek, Baseline Road ditch and Spring Creek. The flux of groundwater to each of these surface water bodies was estimated. The flux of groundwater to Spring Creek (element F) also includes a small amount to the lower part of Bennett Creek.

Groundwater fluxes to the on-site creeks and to the St. Marys River are tabulated in Table 3.11. The range of fluxes shown reflects the temporal range in hydraulic gradient and saturated thickness of the slag unit, and the spatial range in hydraulic conductivity values. Although a range of flux values is shown, the average values are likely to be more representative of actual groundwater discharge rates because these are based on average hydraulic conductivities, thicknesses, and gradients instead of extreme values. The average flux to each of the St. Marys River and the Baseline Road ditch on about $10^5 \text{ m}^3/\text{yr}$ and to Bennett Creek and Spring Creek is about $10^4 \text{ m}^3/\text{yr}$. The average flux to the West Davignon Diversion is much less ($10^3 \text{ m}^3/\text{yr}$) because groundwater discharges through the lower permeability, shallow silty sand and till instead of slag (slag is unsaturated), to the diversion channel.

The fluxes described above are based exclusively on observed hydraulic gradients and hydraulic conductivities at the slag site, and do not account for water balance. An alternate approach to estimating discharge rates is to consider the water balance for the unconfined aquifer. Groundwater discharge rates can be estimated by determining the amount of recharge to the aquifer, assuming the water volume in the aquifer remains constant over time. Recharge to the unconfined aquifer is assumed to be strictly infiltration (neglect groundwater discharge from the underlying aquitard). An infiltration rate of 0.4 m/yr (mean annual precipitation rate of 0.9 m and an assumed evapotranspiration of about 55%). Detailed recharge calculations are provided in Appendix 8 and summarized in Table 3.12. Disposal of pickling liquor and oily water would contribute a recharge of about $1.7 \times 10^4 \text{ m}^3/\text{y}$.

Although locally significant, this recharge is only 1% of the precipitation recharge of $1.6 \times 10^6 \text{ m}^3/\text{yr}$ and is, therefore, insignificant when considering the entire Algoma slag site.

Groundwater flow values provide better estimates of off-site movement than infiltration fluxes, because both infiltration and regional discharge components of flux are incorporated into the estimation procedure by using the total volume of water moving in the groundwater regime.

Despite uncertainties in the estimation methods, the estimates of groundwater flow through the shallow subsurface appear to be reasonable compared to annual infiltration volumes. Uncertainties and possible sources of error in the flux calculations include:

- the estimate of the hydraulic conductivity of the slag, which may be highly variable across the site (\pm one order of magnitude);
- the horizontal hydraulic gradients, which are subject to short-term fluctuations due to river level changes and on-site effluent disposal and seasonal variations ($\pm 10\%$);
- the cross-sectional and plan-view areas, which were approximated from Figure 3.20 by using simple geometric shapes ($\pm 20\%$); and
- annual precipitation and evapotranspiration rates, which are also highly variable ($\pm 50\%$).

3.5.9 Groundwater Velocities and Residence Times

The average linear velocity (v) of groundwater flow can be estimated using the relationship:

$$v = \frac{ki}{n}$$

where: k = hydraulic conductivity (L/T),
 i = horizontal hydraulic gradient (L/L), and
 n = porosity (L^3/L^3).

The average linear horizontal velocity of groundwater movement through the unconfined and confined aquifer units was estimated to provide an estimation of the rate of movement of dissolved materials from the source areas to the site perimeter. Table 3.13 summarizes the groundwater velocity calculations. Average groundwater velocities were calculated using average hydraulic conductivity (Table 3.6) and hydraulic gradient (Table 3.7) values while the range of velocities shown were calculated using maximum and minimum measured hydraulic conductivities (Table 3.6) and hydraulic gradients (Table 3.7). Porosity values, which vary within small limits, were based on typical values given by Freeze and Cherry (1979).

The average horizontal groundwater velocity beneath the western part of the site (near watertable mound) is on the order of 60 to 90 m/yr through the unconfined aquifer and 3 to 200 m/yr through the confined aquifer. Beneath the eastern part of the site where gradients are lower, groundwater flow through the unconfined aquifer is on the order of 20 to 30 m/yr, and is 1 to 60 m/yr through the confined aquifer. The average velocities presented on Table 3.13 are most likely to be representative of groundwater flow conditions beneath the site, however, Table 3.13 also shows a range of velocities for each geologic unit. Minimum velocities, calculated using actual minimum gradients and hydraulic conductivity values and estimated maximum porosities, are about two to three orders of magnitude less than the average values. Similarly, maximum velocities, calculated by using maximum gradients and hydraulic conductivity values and minimum porosities are about two orders of magnitude larger than the average values. Based on average groundwater velocity, water entering the shallow groundwater system at the watertable mound would take approximately ten to fifteen years to move to the shoreline.

Groundwater movement through the aquitard is primarily in the vertical direction and can be estimated using the equation provided above, however, vertical hydraulic conductivity and hydraulic gradients must be used in the calculation. Vertical hydraulic conductivity was not measured in the field, but is typically about an order of magnitude less than horizontal hydraulic conductivity values (Freeze and Cherry, 1979). The upward vertical groundwater velocity through the aquitard is likely to be about 0.009 to 0.6 m/yr while the downward velocity near the watertable mound would be 0.005 to 0.3 m/yr (see Table 3.13).

3.6 Groundwater Chemistry

3.6.1 Introduction

Groundwater samples were collected from 33 monitoring wells installed during this investigation approximately every three months. Samples were analysed for constituents identified by leach testing several of the materials disposed at the site (see Chapter 2.0). Sub-section 3.2.4 describes the approach to parameter selection for chemical analyses. This section describes the chemistry of the groundwater beneath the site and the horizontal and vertical distribution of selected dissolved constituents in the groundwater. This information, together with groundwater flux information presented in Sub-section 3.5.8, provides the basis for estimation of mass flux of selected dissolved constituents from the Algoma slag site.

To facilitate discussion of groundwater quality, the Algoma slag site monitoring wells have been divided into three groups according to their locations: source area wells, perimeter wells and north site wells. The source area and perimeter wells groups have been further subdivided into shallow and deep wells. The north site group consists of only four wells so further subdivision was not warranted. Table 3.14 indicates to which groups the monitoring wells belong.

The chemical data are statistically summarized in Tables 3.15 through 3.19. These tables were prepared using all chemical data from the wells within a given area. The detailed analytical data upon which the summary tables are based are located in Appendix 6. Sample concentrations reported by the laboratory as below the analytical detection limit were assumed to be zero for calculation purposes. Federal health-based drinking water guidelines (Maximum Acceptable Concentration or "MAC") are presented for comparison purposes. Where federal drinking water guidelines are not available, other regulatory guidelines or criteria are presented. Provincial Water Quality Objectives (PWQO) are also presented on the summary tables for comparison purposes because of the concern for aquatic life in the receiving waters.

3.6.2 Analyses of Trip Blanks

Chemical analyses of trip blanks (laboratory prepared bottles containing de-ionized water which were shipped and analyzed with the samples) was conducted for each sampling round. The results of trip blank analyses are included in Appendix 6. Generally most parameters analyzed for were not detected; however, the Summer 1988 trip blank contained low concentrations of dissolved inorganic carbon (1 mg/L), alkalinity (2 mg/L), phenols (0.003 mg/L), oil and grease (2 mg/L), cadmium (0.004 mg/L), and iron (0.02 mg/L). This trip blank also contained detectable levels of two PAHs (0.05 µg/L naphthalene and 0.03 µg/L phenanthrene). The trip blank for the Fall 1988 sampling session contained low concentrations of cations (calcium 0.5 mg/L, magnesium 0.1 mg/L and potassium 0.05 mg/L).

3.6.3 General Groundwater Quality - North Site Area

The monitoring wells located north of Baseline Road ditch (wells A5, A6 and well nest A7) are located regionally upgradient relative to other monitoring wells on the site. The groundwater quality at location A7 is indicative of background conditions. Wells A5 and A6 are located in a slag fill area, thus the shallow groundwater quality at this well is somewhat affected by on-site conditions. The chemical data for the north site area wells is summarized in Table 3.15.

General Indicators and Anions

The groundwater from the north site area was generally slightly alkaline (pH of 7.9 to 9.4), but was very alkaline at well A5 (pH from 11.1 to 12.3). Similarly, groundwater from A5 had a higher specific conductance (600 to 1730 $\mu\text{S}/\text{cm}$) than the groundwater from the other north site wells (180 to 610 $\mu\text{S}/\text{cm}$). Alkalinity, bromide, chloride, and fluoride concentrations were also elevated in samples from A5 relative to the other samples. Chloride concentrations were highest in the samples from A5 (15.6 to 18.3 mg/L) but A6 and A7-1 also had similar, slightly lower chloride concentrations (10.1 to 14.1 mg/L). The samples from A7-2 had much lower chloride concentrations (1.49 to 1.69 mg/L). Cyanide was only detected in two samples from well A5. The total cyanide concentration of these two samples (0.008 and 0.015 mg/L) exceeded the PWQO for cyanide (0.005 mg/L).

Metals

Metals concentrations in the north site groundwater were generally low. Cobalt, lead, beryllium and selenium were not detected in any of the samples analyzed for these metals. Samples from well A5 generally contained the maximum metals concentrations. MAC values were exceeded by one sample containing detectable nickel and by four samples containing detectable aluminum. Cadmium, copper, iron and aluminum concentrations exceeded PWQO's for these metals. These metals occurred in groundwater samples other than from well A5 at concentrations in excess of the PWQO's indicating their likely presence in background groundwater.

Nutrients

Nitrate was detected in most groundwater samples. A sample from A7-1 maximum nitrate concentration (0.68 mg/L). A sample from A7-1 also had the maximum ammonia concentration (0.55 mg/L) but only two samples were collected for ammonia analyses. Both

of these had ammonia in excess of the PWQO value. The number of TKN and phosphate analyses was also limited. Samples from A5 had the highest concentrations of these nutrients (TKN 18.2 mg/L, total phosphorus 0.10 mg/L). All samples with detectable phosphate had concentrations in excess of the PWQO for phosphate.

Organic Compounds

DOC and oil and grease concentrations were low (up to 40 and 3.0 mg/L respectively). The two samples from well A7-1 which were analyzed for PCBs did not contain detectable PCB concentrations. Phenols concentrations were generally low (up to 0.006 mg/L) except for well A5 which had much higher concentrations (0.125 to 0.143 mg/L). Although phenols concentrations in excess of the PWQO (0.001 mg/L) are reported for background wells A6 and A7-2, these concentrations are slightly above the detection limit of 0.001 mg/L and are about at the same concentration as found in the trip blank. Phenols concentrations at A5 were higher -- in excess of 100 times the PWQO.

The samples from the north site wells did not contain detectable BTX, except for the sample from A7-2 (total BTX 126 µg/L). Well A7-2 is located on the northern perimeter of the site and the presence of low quantities of BTX here may indicate the migration of BTX onto the Algoma slag site through the shallow groundwater system.

Samples from A5 and A6 had low concentrations of PAHs (0.20 to 14.27 µg/L). Samples from nested wells A7-1 and A7-2 did not contain detectable PAHs.

3.6.4 General Groundwater Quality - Shallow Source Area

The central disposal area, located on the topographically high part of the site which is underlain by the watertable mound, is considered to be a source area for constituents to the groundwater. Monitoring wells A1 (located near the oil pond) and A2 (near the decanter sludge dump) are within this source area. Monitoring wells A3, A4 and D6, and all C-series wells are located adjacent to the base of the slag escarpment and are likely to also be indicative of source or near-source conditions. Previous investigations (GLL, 1988; CRA, 1988) and drilling during this investigation indicated the presence of tarry materials in the subsurface in the vicinity of the former Domtar facility. This area, including monitoring well B1, is also considered a source area because of the presence of tarry materials at this location. Several of the well locations listed above are monitoring well nests. Only the shallow well at the nest is included in the shallow source area wells group. All other single well installations listed above are included in this group. Table 3.14 gives a complete listing of the wells included in this group. Table 3.16 summarizes the chemical data for the shallow source area wells.

General Indicators and Anions

The shallow groundwater from the source area monitoring wells had a highly variable chemical composition. The groundwater ranged from slightly acidic (pH 6.3) to very alkaline (pH 12.2). The range of detected concentrations of most parameters is very large -- most parameters vary by one to three orders of magnitude as a result of the spatial variability of the groundwater chemistry. Generally, the samples from well A1-2 contained the maximum concentrations of major anions. Cyanide and fluoride were detected in most (85% and 97%) of the samples collected from the shallow source area. A sample from A1-2 had the maximum fluoride concentration while a sample from A2-2 had the maximum total cyanide concentration. Fluoride (13 samples), sulphate (17 samples), and total cyanide (3 samples) concentrations exceeded drinking water criteria. The total cyanide concentrations for 10 samples also exceeded the PWQO.

Metals

Metals concentrations in the shallow source area groundwater were quite spatially variable. Beryllium and selenium were not detected in any samples. PWQO's for zinc, cadmium, copper, iron, aluminum, lead mercury and nickel were exceeded by several samples. Cadmium, lead, chromium, aluminum and nickel concentrations also exceeded drinking water limits. The groundwater samples from A1-2 generally contained the maximum metals concentrations.

It is interesting to note that, although cadmium did not appear to leach from any of the materials tested (Section 2.2), it was found at low $\mu\text{g/L}$ levels in the shallow source area groundwater. This apparent discrepancy may be due to utilizing higher detection limits during the leachate analysis (0.005 mg/L for leachate compared to 0.0002 mg/L for groundwater). Cadmium was generally only detected in the groundwater samples collected during the first sampling session (Summer, 1988). Cadmium was also detected in the trip blank for the Fall 1988 sampling session which suggests its presence in the groundwater samples was likely a laboratory artifact.

Nutrients

Ammonia and phosphorus were detected in most of the samples which were analyzed for these parameters. Comparison of the TKN and ammonia concentrations indicates that ammonia nitrogen comprises a variable proportion of the TKN (approximately 4 to 80%). The maximum nutrients concentrations occurred in samples from A1-2. Ammonia and phosphorus concentrations exceeded PWQO values for several samples.

Organic Compounds

DOC concentrations were variable, with the maximum occurring for the groundwater sample from A1-2. No PCBs were detected in the five groundwater samples collected from C4, B1 and A1-2. No other samples were analysed for PCBs.

Phenols were detected in groundwater samples from most shallow source area wells (except wells C2-1 and A3). Groundwater samples from well A1-2 contained the highest phenols concentrations (1.4 to 3.8 mg/L); however, groundwater from wells A2-2, B1 and C3 also contained high phenols concentrations (0.009 to 0.4 mg/L compared with up to 0.008 for other wells). All but one sample (with detectable phenols) had phenols concentrations in excess of the PWQO value for phenols. Samples obtained from A1-2, B1 and C4 were the only samples analysed for phenol species. Phenol (proper) and cresols comprised the phenol species. No chlorinated phenols were identified.

Total VOC concentrations ranged from 26.2 to 82,167 µg/L. The volatiles were generally comprised of aromatic hydrocarbons; however, low concentrations of chlorinated aliphatics (20 µg/L trichloroethene) and halomethanes (23 µg/L) were detected in groundwater samples from monitoring wells A2-2 and C4. VOC analyses were subsequently replaced by BTX analyses after the Summer 1988 sampling round. Only five of the shallow source wells (A1-2, A2-2, B1, D6, and C4) were sampled for BTX. All five wells had samples with detectable BTX with the sample from A1-2 (near oil pond) having the maximum total BTX concentration. The presence of BTX in groundwater at these locations is consistent with the presence of oily and/or tarry materials on or below the surface in these areas.

PAHs were detected in samples obtained from monitoring wells A1-2, A2-2, B1 and C4 at total concentrations that ranged from 0.7 to 8886.8 µg/L, but were not detected in the groundwater from A4-2 or D6. The sample from well B1 had the maximum PAH concentration, consistent with the presence of tarry material in the subsurface at this location. The light and medium weight PAHs were the most frequently detected and occurred at the

highest concentrations, but all PAHs were detected in at least three samples from two locations.

3.6.5 General Groundwater Quality - Deep Source Area

As described in sub-section 3.6.4, the central disposal area, and area around and including the former Domtar facility are considered to be potential source areas for constituents in groundwater. Monitoring wells installed in the deep groundwater system in these areas are A1-1, A2-1 and A4-1. Table 3.17 summarizes the chemical data for the deep source area wells.

General Indicators and Anions

Groundwater from the deep source area was slightly alkaline (average pH 8.0). The specific conductance was generally low (150 to 620 $\mu\text{S}/\text{cm}$) except at A1-1 (4440 to 9590 $\mu\text{S}/\text{cm}$) which results in the large average presented in Table 3.17. Similarly, the concentrations of anions were low (up to 5.5 mg/L for bromide, chloride, fluoride and nitrate; up to 114 mg/L for sulphate) except at for A1-1. Samples from A1-1 contained elevated chloride (1150 to 1870 mg/L), fluoride (up to 3.5 mg/L), and sulphate (1400 to 1600 mg/L). These high anion concentrations are likely due to the close proximity of well A1-1 to the acid (pickling liquor) and lime fines disposal area.

The four samples from A1-1 had sulphate concentrations in excess of the MAC for sulphate. Two of these four samples also had fluoride concentrations in excess of the MAC. Also, the one sample with detectable cyanide had a cyanide concentration in excess of the PWQO for that constituent.

Metals

Concentrations of metals in the source area deep groundwaters were generally quite variable. Only beryllium was not detected (arsenic, selenium and mercury were not analyzed for). The maximum metals concentrations generally occurred in samples from well A1-1, consistent with the location of maximum anion concentrations. Two samples had nickel and one sample had aluminum and lead concentrations in excess of drinking water guidelines. Zinc, cadmium, copper, iron, lead and nickel concentrations at A1-1 exceeded PWQO's. In addition, one sample from each of A2-1 and A4-1 had copper concentrations which exceeded the PWQO value.

Nutrients

Few samples were analyzed for TKN and phosphorus (two and one sample respectively) and no samples were analyzed for ammonia. The one sample analysed for total phosphorus had a concentration in excess of the PWQO. Nitrate concentrations were up to 2.0 mg/L, with the maximum concentration occurring in a sample from A1-1.

Organic Compounds

DOC and phenols concentrations were generally low (1.0 to 3.5, and up to 0.004 mg/L respectively), except for A1-1 (165 to 200, and 0.88 to 4.8 mg/L respectively).

Only two samples were analyzed for BTX -- the sample from A4-1 contained a total BTX concentration of 36 µg/L and the sample from A1-1 contained 70,313 µg/L. The presence of BTX in the samples from A1-1 suggests that the presence of the nearby oil pond has affected the deep system at this location.

The PAHs concentrations of deep groundwater samples from the source area were low (total PAHs of 0.02 to 5 µg/L) with the maximum concentration occurring at A1-1. The sample from A2-1 contained only 0.02 µg/L naphthalene; no other PAHs were detected in this sample. This PAH level is similar to the concentration contained by the trip blank and is likely to be a laboratory artifact. Two samples from A4-1 did not contain detectable PAHs.

Summary

Deeper groundwater within the source area generally had lower concentrations of most dissolved constituents relative to the shallow source groundwater and show little effect of disposal practices. This is likely due to the strong upward-directed gradients which prevent affected groundwater from entering the deep system. One notable exception to this lack of impact occurs at location A1 where a downward gradient was measured. Here, the deep groundwater had nearly triple (1,150 mg/L) the chloride of the shallow water (440 mg/L) and also had elevated metals, DOC, phenols and BTX. This distribution is likely due to the disposal of hydrochloric acid nearby. Downward-directed gradients and the density of the acid would cause it to move to the base of the permeable zone creating a deep chloride source locally. The deep groundwater at A1 also had a higher BTX concentration which suggests water from the oil pond may also move to the deep system at this location. Vertical groundwater flow directions beneath the site indicate that this water will mix with upward-flowing groundwater beneath the site and will discharge to the St. Marys River.

The absence of significant contamination at A4-1 is consistent with the results of tritium analyses which indicate that groundwater at A4-1 was recharged prior to the 1950's. Low concentrations of BTX (36 µg/L) were detected in one sample from A4-1; however, it is uncertain whether this BTX was really present in the deep groundwater or whether it is contamination by the shallow subsurface during drilling.

3.6.6 General Groundwater Quality - Shallow Site Perimeter

Perimeter area wells include the B-series (except for B1) and all D-series installations. Only the shallow monitoring wells are included in this discussion (see Table 3.14). Table 3.18 is a summary of the groundwater chemistry of this area.

General Indicators and Anions

The indicator parameters and major anions show a wide range of values for the shallow groundwater around the site perimeter as a result of their spatial variability. The groundwater pH ranged from neutral (pH 7.0) to very alkaline (pH 12.9). Specific conductance ranged from 900 to 7950 $\mu\text{S}/\text{cm}$. The major anions show concentration ranges of one to two orders of magnitude. The maximum concentrations did not occur consistently at any one well (see Table 3.18). Fluoride concentrations at three wells (B2-2, D5 and D6), sulphate at three wells (D4, D5 and D6) and cyanide at two wells (D3-2 and D5-2) exceeded drinking water MAC values. Cyanide at all wells except D1-2 exceeded the PWQO.

Metals

Lead and beryllium were not detected in any of the groundwater samples collected from the shallow wells along the site perimeter. Samples from D5-2 generally contained the maximum metals concentrations. Drinking water criteria were exceeded by cadmium (one of 34 samples), nickel (14 of 34 samples) and aluminum (23 of 24 samples) concentrations. Two (of 34) zinc, one (of 34) cadmium and all aluminum (24 total) concentrations exceed PWQO's for these metals.

Nutrients

Nitrate was detected in relatively few of the groundwater samples from the shallow site perimeter (12%); however, ammonia, TKN and phosphorus were detected in virtually all (91

to 100%) of the samples. Samples from D5-2 (nitrate, TKN and phosphorus) and D3-2 (ammonia) had the maximum nutrients concentrations. Ammonia comprised 64 to 75% of the TKN. All samples analyzed for ammonia and several samples analyzed for phosphorus had concentrations in excess of PWQO values.

Organic Compounds

DOC, oil and grease, and phenols minimum and maximum concentrations vary by about a factor of ten. Samples from D6 had the maximum DOC (32 mg/L) and oil and grease (7 mg/L) concentration while D3-2 had the maximum phenols concentration (0.080 mg/L). All wells had samples with phenols concentrations which exceeded the PWQO (0.001 mg/L).

The three samples collected from D1-2 and three from D3-2 did not contain detectable PCBs. No other samples were analysed for PCBs. These wells were selected for PCB analysis because of their proximity to the PCB storage facility.

Samples from B2-1, B2-2 and D3-2 were analyzed for volatile organic compounds. The VOCs detected in B2-1 and D3-2 were comprised predominantly of halogenated methanes with a trace of tetrachloroethene (2.4 µg/L) in D3-2. Sample B2-2 had no detectable VOCs. No aromatic hydrocarbons (e.g. BTX) were detected.

All perimeter wells were sampled for PAH and BTX analyses. BTX was detected in groundwater samples from B3, B4-2, B5, D2, D3-2, D5-2 and D6. The sample from D2 had the maximum total BTX concentration (65 µg/L). PAHs were detected in groundwater samples from all wells (total PAHs 0.7 to 61 µg/L) except the two samples from D6. All PAHs, except dibenzo(a,h)anthracene were detected at least one time. The light and medium-weight PAHs were the most frequently detected. Naphthalene occurred at concentrations up to 10 times the maximum concentration of other PAHs.

Comparison to Source Area Wells

Maximum concentrations for perimeter wells were significantly lower than for source wells. Lower maximum concentrations were found for a number of parameters, including specific conductance, DOC, sulphide, sulphate, fluoride, TKN, phenols, oil and grease, PAHs and BTX. Metals present at significantly lower peak concentrations include zinc, manganese, iron, lead, aluminum, magnesium, potassium, strontium and sodium. Although concentrations were lower than those in the source areas, a number of environmental guidelines were exceeded (Table 3.18). Of particular note are the large number of samples with concentrations which exceed the cyanide, phenols and metals PWQO's, and the presence of PAHs (up to 61 µg/L) and volatile organics (total BTX up to 65 µg/L).

3.6.7 General Groundwater Quality - Deep Site Perimeter

The deep monitoring wells of the B and D series (except B1) are designated as deep site perimeter wells. This designation consists of deeper wells at well nests B2, B4, D2, D3 and D5 (see Table 3.14). The groundwater chemistry for these wells is summarized in Table 3.19.

General Indicators and Anions

The deep groundwater around the site perimeter was neutral to alkaline (pH 7.1 to 11.7) and ranged from slightly to highly conductive (specific conductance 190 to 5950 µS/cm). Groundwater samples from the deep wells at locations D1, D3, and D5 had high chloride concentrations (136 to 1,530 mg/L) relative to other deep groundwater samples from the site perimeter (11.1 to 31 mg/L). Deep groundwater samples from D1 and D5 also had higher sulphate concentrations (186 to 970 mg/L) than the other deep groundwater samples (11.5 to 45.0 mg/L). Two samples contained detectable cyanide concentrations (0.008 and 0.93 mg/L at D5-1). One and both of these samples exceed PWQOs and MACs respectively. The cyanide concentration of 0.93 mg/L is inconsistent with the later sample with a concentration

of 0.008 mg/L and appears to be a laboratory error. The sulphate and chloride concentrations reported for the sample containing the high cyanide concentration are also very high and inconsistent with other data for this well. Consequently, these data are also suspect.

Metals

The metals concentrations were generally quite low; however, the groundwater samples from D1, D3 and D5 had higher concentrations than the samples from other deep perimeter wells. The maximum concentrations of most metals occurred in samples from for D3-1. Zinc and nickel (one sample each), cadmium and copper (five samples each), and iron and aluminum (eight samples) concentrations exceeded PWQO's. Drinking water criteria for nickel and aluminum were exceeded by seven and six samples respectively. Lead and beryllium were not detected in any of the groundwater samples while analyses were not conducted for arsenic, selenium and mercury.

Nutrients

The concentrations of nutrients were spatially variable. The maximum concentrations of all parameters were not at any one well. All samples analyzed for total phosphorus had concentrations in excess of the PWQO.

Organic Compounds

DOC concentrations have trends similar to the metals and major anions -- concentrations at D1, D3 and D5 are much higher (2.3 to 14.0 mg/L) than the other wells (0.5 to 0.8 mg/L). Phenols concentrations are generally low at all wells, with the maximum concentration (0.015 mg/L) occurring at B4-1. Eight samples had phenols concentrations which exceed the PWQO (0.001 mg/L).

Three samples were collected from well D1-1 (located downgradient from the PCB storage area) for analysis of PCBs. One sample had detectable PCBs (0.012 µg/L Arochlor 1254) but subsequent samples from the well had PCB concentrations below the detection limit. The concentration identified in the one sample is below the Interim Maximum Acceptable Concentration (IMAC) for drinking water (3 µg/L) but above the PWQO (0.001 µg/L).

BTX were detected in groundwater samples from D1, D3, D5 and B2 but the concentrations measured were low (total BTX ranging from 2 to 32 µg/L). Low concentrations of PAHs (total PAHs 0.1 to 20.4 µg/L) were detected in samples from all wells except D3 and B2-3. The first sample obtained from B2-1 had the maximum total PAH concentration (20.4 µg/L) while the three subsequent samples collected from this well had no detectable to very low (0.2 µg/L) PAHs. The absence of PAHs in subsequent samples suggests the first sample to be anomalous or erroneous. The presence of PAHs in the first sample may be the result of surface contamination of the deep confined aquifer during drilling. The shallow groundwater from this location was found to contain low concentrations of PAHs (B2-2 had total PAH concentrations of 0.7 to 1.5 µg/L). Although drilling techniques were employed to prevent this from occurring, it is possible that contamination from the shallow subsurface was dragged down the borehole during drilling.

3.6.8 Temporal Variability of Groundwater Samples

Groundwater samples were collected from wells A7-1, C4, and D3-2 for detailed chemical characterization (Level 3 analyses) to provide an indication of the temporal variability of groundwater quality in the north site, source and perimeter areas respectively. Samples for only two Level 3 analyses were collected from A7-1 because the well was frozen during the winter sampling session and a Level 1 analysis was conducted for the first sampling round. Wells C4 and D3-2 were sampled during each of the four sampling events for Level 3 analyses:

The temporal range of concentrations for each well are provided in Table 3.20. The groundwater chemistry of A7-1 exhibited very little temporal variation as the maximum and minimum concentrations of most parameters are similar in concentration. Parameters with significant variation (maximum and minimum differ by more than a factor of three) include fluoride, nitrate, ammonia, manganese, iron and mercury. The reason for the variability is uncertain. No particular temporal trend is apparent.

The samples from D3-2 show consistency with time. Only manganese concentrations varied by more than a factor of three. All other parameters had maximum and minimum concentrations which differ by less than a factor of three.

The samples from C4 show the most temporal variability. Sulphide, total cyanide, ammonia, phosphorous, zinc, iron, aluminum, arsenic, mercury, BTX and PAH concentrations vary by over a factor of three with time. C4 is located near the source area and, therefore, is likely to have a fluctuating groundwater chemistry because of the nature of the source of most of the constituents in the water. A fluctuating input, both in terms of volume and concentration, would produce this type of fluctuation in groundwater chemistry.

The consistency of the groundwater chemistry at perimeter well D3-2 is significant. Other site perimeter wells also show general consistency of groundwater quality with time although detailed analyses were not conducted on those samples. Mass flux estimates can be based on average groundwater quality data, without having to account for temporal variation in the flux rates.

3.7 Distribution of Dissolved Constituents

The spatial distribution of selected indicator parameters and parameters of environmental concern are examined in this section to identify off-site migratory potential and pathways. The distribution of pH and chloride were examined because these are indicators of pickling

liquor disposal which may mobilize metals in the subsurface. Specific conductance was examined in order to correlate on-site groundwater quality with the off-site sediment survey described in Chapter 4.0. The distribution of sulphates, phenols, BTX, PAHs and total cyanide were examined in detail because these constituents were identified in groundwater samples from the site perimeter at levels of environmental concern (i.e. concentrations in excess of either MACs or PWQO's). Zinc, cadmium, iron, nickel, and aluminum distributions were examined because these metals were identified in groundwater samples from the site perimeter at concentrations of environmental concern.

The seasonal chemical data obtained during this investigation were averaged to give an annual average for each well. The figures discussed in this section were prepared using the average concentrations. The average concentrations and results of individual analyses are located in Appendix 6.

3.7.1 pH

The pH distribution in the shallow groundwater, illustrated in Figure 3.21, is dominated by a neutral zone corresponding to the central area of the slag site (or source area). The shallow groundwater generally becomes more alkaline with increasing distance from the source. This distribution may be attributed to the interaction of two processes: hydrochloric acid disposal at the acid dump and the chemical evolution of groundwater in slag. The source area is of neutral pH because large volumes of pickling liquor are disposed at the acid dump. Neutralization of the acid by reaction with lime fines and slag results in infiltration of water with near neutral pH.

Slag contains a high percentage of calcium oxide. When water comes in contact with the slag, the following reactions occurs:



The solution pH is controlled by the dissolution of slaked lime ($\text{Ca}(\text{OH})_2$) and rises because of the increased hydroxyl ion concentration. The equilibrium pH of this system is about 12.2, which is consistent with the pH of the alkaline water at the site perimeter.

Figure 3.21 also indicates the pH of deeper groundwater; however, the data have not been contoured. The deeper groundwater generally had lower pH values (6.4 to 10.4) than the shallow groundwater. Flow patterns (Figures 3.10 and 3.11) indicate the deeper groundwater generally has not been in contact with slag and, therefore, has not undergone the chemical evolution causing pH elevation.

3.7.2 Specific Conductance

Figure 3.22 illustrates the distribution of specific conductance. The specific conductance of the groundwater beneath the slag site is high, particularly to the south of Baseline Road. Specific conductance is generally proportional to total dissolved solids (TDS); however, in solutions of high pH, specific conductance is high and seems unrelated to TDS concentration. This effect occurs because the conductance of the hydroxyl ion (OH^-) is much greater than that of other anions.

Specific conductance values for shallow groundwater are highest at A1, D4 and D5 (Figure 3.22). The trend at A1 extending southward the St. Marys River at B4 and B5 is likely associated with the disposal and subsequent movement of the pickling liquor. High specific conductance values along the western shoreline (at D4, and D5) decrease towards the east. This trend is contrary to that expected if the source of the conductivity was the central slag pile. Another source of high TDS (possibly dredged river sediments) may be located in this area.

Specific conductance values for the deep groundwater are also indicated on Figure 3.22. Deep groundwater had a lower specific conductance than the overlying shallow groundwater except

at locations D3 and A1. Groundwater from beneath the laminated silt and clay aquitard on the eastern part of the site had a much lower specific conductance (193 to 350 $\mu\text{S}/\text{cm}$) than deep groundwater where the laminated clay and silt is absent (520 to 6,715 $\mu\text{S}/\text{cm}$).

3.7.3 Chloride

The chloride distribution in shallow groundwater is illustrated in Figure 3.23. A very regular chloride plume extends southeastward from wells A1 and C4 near the acid dump toward the St. Marys River shoreline to the east and the west Davignon Diversion. The high chloride concentrations in shallow groundwater are likely due to disposal of pickling liquor (hydrochloric acid). The location of the chloride plume generally correlates well with a zone of high specific conductance (Figure 3.22).

Groundwater with high chloride concentrations also occurs beneath the Baseline Road ditch (see Section 3.8.3) which suggests some of the acid-affected water moves northward. High chloride concentrations did not occur at well A5 to the north of the Baseline Road ditch which indicates that the northward movement of acid-affected water is limited, likely because it discharges to the ditch.

Groundwater samples from below the laminated silt and clay aquitard within the chloride plume had much lower chloride concentrations (14 to 28 mg/L) than those samples from above the silt unit. Also, where the clay is not present within the chloride plume (at A1 and D1), the deeper groundwater exhibited higher chloride concentrations than the overlying groundwater. Chloride in the deep groundwater near the chloride source (A1) is likely higher than in the shallow groundwater because of the high density of the waste acid causing it to sink to the bottom of the permeable zone. The higher chloride concentration of the deeper groundwater at D1 can be explained by screen position and recharge. The screen of well D1-1 is installed in the shallow silty sand beneath the slag. Although this unit is considered to be part of the aquitard beneath the western part of the site, it is much more permeable than the

laminated clay and silt unit to the east. The presence of high chloride in the upper part of this unit is not surprising. The presence of lower chloride concentrations in the slag above this unit is likely due to dilution at the watertable by infiltrating water.

Deep groundwater at D3 was also found to contain a very high chloride concentration (1,453 mg/L). This is not likely to be attributed to recent disposal of pickling liquor since groundwater flow directions from the acid pit are not apparently in this direction. The reason for this chloride concentration is unclear but this could be due to historic (pre-1953) transport of acid-affected water under different flow conditions.

3.7.4 Sulphate

The distribution of sulphate in the shallow groundwater is illustrated in Figure 3.24. High sulphate concentrations were identified in groundwater from wells A1, C1, C2, D4 and D5 (see 1000 mg/L isoconcentration contour on Figure 3.24). These high levels are likely due to the dissolution of gypsum in the lime fines by infiltrating pickling liquor and rainfall. Elevated sulphate levels occur in most wells downgradient from the lime fines area, while regionally upgradient wells had much lower concentrations (2.3 to 30 mg/L). Groundwater from beneath the Baseline Road ditch also had high sulphate concentrations (see Section 3.8.3) indicating that groundwater from the slag pile moves northward to Baseline Road as well as to the south and west.

Deep groundwater from the confined aquifer beneath the laminated clay and silt aquitard contained sulphate levels (6.6 to 18 mg/L) similar to the regionally upgradient wells. West of the clay and silt, the deep groundwater contained slightly higher sulphate levels (27 to 1,542 mg/L). Again, the presence of a less effective aquitard below the western part of the site appears to be the cause of these higher concentrations. The shallow part of the aquitard is affected by the shallow groundwater (for example, wells A1-1 and D1-1) but the deeper part of the aquitard has not been affected (for example, D3-1).

3.7.5 Phenols

Figure 3.25 illustrates the distribution of phenols in the shallow groundwater. Deep groundwater phenols concentrations are also shown, however, these data are not contoured. The shallow groundwater at A1 contained the highest total phenols concentrations (average phenols concentration 2.488 mg/L). A zone of high phenols concentrations (greater than 0.010 mg/L) in shallow groundwater extends southwest to northeast across the site coincident with the locations of perceived source areas. The phenols concentrations in the shallow groundwater decrease sharply to below 0.010 mg/L away from this zone, but then increase again at perimeter wells D3 and D4. This concentration decrease is sharper than the gradual decrease exhibited by the chloride, specific conductance and sulphate distributions. The sharper decrease suggests that phenols are being removed from, rather than simply dispersed in, the subsurface. Phenols are readily degradable compounds. Removal by biodegradation would result in sharp concentration decreases with distance from the source areas.

Deep groundwater had lower phenols concentrations than the shallow groundwater. Phenols concentrations were up to 0.006 mg/L, except at A1-1 (2.41 mg/L).

3.7.6 BTX and PAHs

The distribution of total BTX and total PAHs in groundwater is illustrated in Figure 3.26. The data are not contoured because no information is present for several C-series wells located between the source areas and site perimeter.

Source areas for BTX and PAHs to the shallow groundwater appear to be the central disposal area and the former Domtar and surrounding area. BTX and PAHs concentrations decrease downgradient from these areas, however, BTX and PAHs occur in the groundwater along the site perimeter. The widespread occurrence of BTX and PAH may be in part due to the previous practice of oil-spraying roads on-site for dust control.

Previous hydrogeologic investigations of the former Domtar facility (GLL, 1988) and surrounding area (CRA, 1988) identified BTX and PAH concentrations in groundwater from this area of up to 3160 and 7422.8 µg/L respectively. These high concentrations are consistent with the concentrations indicated for well B1. With the exception of the source areas, BTX and PAHs concentrations in the deep groundwater were lower (up to 36 µg/L for BTX; up to 5.1 µg/L for PAHs) than the shallow overlying groundwater (up to 126 µg/L for BTX and up to 42.2 µg/L for PAHs around the site perimeter).

3.7.7 Total Cyanide

Figure 3.27 shows the concentration of total cyanide in the shallow and deep groundwater beneath the Algoma slag site. Two areas contain groundwater with high total cyanide concentrations: the area near wells D2 and D3 (0.159 and 1.665 mg/L respectively) and the area near wells A2, D5 and D6 (0.106 to 0.195 mg/L). Source areas for the cyanide are uncertain but appear to be associated with the central slag area (sludge dump area) and the dredged sediments.

3.7.8 Metals

Figure 3.28 illustrates the distribution of zinc, cadmium, iron, nickel and aluminum concentrations in the groundwater beneath the Algoma slag site. The highest metals concentrations occur in the shallow groundwater at well A1 near the oil pond. Metals concentrations decrease sharply away from this area, likely because of the increasing pH of the groundwater. Zinc and cadmium concentrations are variable around the site perimeter. Iron concentrations are two to three orders of magnitude higher between the oil pond area and West Davignon Diversion than elsewhere on-site. Nickel concentrations are fairly consistent and low across the site. Aluminum appears to occur naturally in the shallow groundwater -- it is found in the upgradient wells at about the same concentration which occurs in shallow site perimeter wells.

3.7.9 Summary of Solute Distributions

Groundwater contamination appears to be related to three separate source areas: the main slag pile and disposal area, the former Domtar facility and surrounding area, and the dredged river sediment disposal area.

The main slag pile and disposal area seems to be the major source of several indicator parameters in the shallow groundwater on-site. Phenols, sulphate, chloride and specific conductance plumes trend from high concentrations at the slag pile to lower concentrations near the St. Marys River towards the southeast. Relatively undiluted source area groundwater appears to be discharging directly to the West Davignon Diversion and Baseline Road ditch. Groundwater containing cyanide also appears to be discharging to West Davignon Diversion.

PAHs and BTX were found in the shallow and deep source area groundwater at average concentrations up to 70,000 and 38 µg/L respectively. The extent of migration of these compounds from the central disposal area is uncertain because of their tendency to sorb to aquifer material and move more slowly than conservative constituents like chloride. In addition, the widespread use of oil for dust control on-site appears to have caused a widespread occurrence of BTX and PAHs in the shallow groundwater.

The region around the former Domtar facility is another source of subsurface contamination. Tarry materials were found in the shallow subsurface at B1 and have previously been identified in the subsurface (GLL, 1988; CRA, 1988). PAHs and VOCs occurring in the groundwater at B1 and B2 near the boat slip are likely to be associated with the tarry materials.

Dredged river sediments containing oil and grease and zinc were disposed of along the southwest shoreline, and may be the source of PAHs, phenols and VOCs at D3.

Many groundwater samples had ammonia and total phosphorus concentrations in excess of PWQO values for these constituents. Although the slag site is likely to have contributed ammonia and perhaps some phosphorus to the groundwater, shallow and deep groundwater samples from upgradient areas of the site also had problematic ammonia and phosphorus levels. Ammonia and phosphorus may be migrating onto the site from either natural or man-made sources.

Deep groundwater collected in the eastern half of the site occurs in a basal sand and gravel unit below a thick laminated clay and silt aquitard. Water from the basal sand and gravel generally had a much lower specific conductance and concentrations of sulphate, chloride and phenols, indicative of natural groundwater chemistry. Upward directed gradients appear to have prevented the migration of constituents from the shallow regime to the deeper one.

Deeper groundwater occurring in the silty sand and till units to the west of the main slag pile appear to have been impacted, to some extent, by the main disposal area. These units are recharged directly in the vicinity of C2 where the watertable occurs within the natural geologic material rather than the slag. In this way, constituents derived from the slag and associated wastes move into the underlying material under localized downward gradients in the vicinity of C2. This recharge condition may relate to the disposal of pickling liquor at the nearby acid dump.

3.8 Groundwater Quality - Creek Bed Mini-Piezometers

Groundwater samples were collected from seven creek bed mini-piezometers during the Spring 1989 and analysed. These data were collected to aid in determining shallow groundwater flow conditions in the vicinity of West Davignon Diversion and Baseline Road ditch. The chemical data are listed in Appendix 6. The data are discussed by mini-piezometer transect location below.

3.8.1 Location A - West Davignon Diversion

Groundwater samples were collected from mini-piezometers CBA1-1 and CBA1-2. Groundwater from these mini-piezometers was of similar quality to groundwater from monitoring well D6. Although there are some differences in major ion and trace organic chemistries, the groundwater obtained from the mini-piezometers shows similarities to groundwater from the site which confirms that the groundwater from the site migrates to the creeks. Differences in water quality are:

- The sample from mini-piezometer CBA1-1 had a lower pH and higher specific conductance (pH 6.57; specific conductance 4050 $\mu\text{S}/\text{cm}$) than D6 (pH 7.13 to 7.27; specific conductance 2530 to 3170 $\mu\text{S}/\text{cm}$).
- The mini-piezometer and D6 samples had similar major ion chemistries; however, the mini-piezometer samples had lower alkalinities (99 to 112 mg/L CaCO_3 compared to 630 to 760 mg/L CaCO_3) and magnesium (76 versus 100 to 117 mg/L) concentrations and higher sulphate (890 to 1150 mg/L versus 103 to 650 mg/L), manganese (5.2 versus 1.64 to 2.2 mg/L), potassium (54 versus 21 to 24 mg/L), and iron (88 versus 6.1 to 35 mg/L).
- The mini-piezometer and D6 samples had similar phenols (0.006 and 0.012 mg/L for mini-piezometers and <0.001 to 0.008 mg/L for D6) and PAHs (total PAHs 6.5 for CBA1-1 and no detectable PAHs at D6) concentrations. The sample from mini-piezometer CBA1-1 had no detectable BTX while D6 had a total BTX concentration of 62 $\mu\text{g}/\text{L}$.

The chloride, phenols and PAHs concentrations are plotted on the cross-section for this transect (see Figure 3.29) to illustrate the spatial distribution of the groundwater chemistry.

3.8.2 Location B - West Davignon Creek

One groundwater sample was collected from mini-piezometer CBB1-1 located on the east side of West Davignon Diversion (i.e. Algoma slag site side of creek) and a composite sample was collected from CBB2-1 and CBB2-2a located on the west bank. Comparison of the analytical results of these samples indicates:

- The sample from the east bank (CBB1-1) had a higher chloride (200 versus 4.8 mg/L), fluoride (1.8 versus 0.24 mg/L), and sulphate (1,360 versus 37 mg/L) concentration, and lower alkalinity (32 versus 146 mg/L CaCO_3) than the composite sample from the west side of the creek.
- The sample from the east bank had a higher TKN concentration (50 versus 1.92 mg/L).
- The sample from the east bank had a higher phenols concentration (0.017 versus 0.004 mg/L) and lower DOC concentration (13.7 versus 45 mg/L).

Insufficient water was collected from the west bank to enable analysis of metals or trace organics (BTX and PAHs) so comparison of these parameters is not possible. The sample from the east bank contained low concentrations of benzene (2 $\mu\text{g/L}$) and naphthalene (0.2 $\mu\text{g/L}$). Figure 3.30 shows the distribution of chloride and phenols in the vicinity of the creek at transect location B. The chemistry of the water from the east bank mini-piezometer is significantly different from the chemistry of the water from the west bank, but is similar to groundwater below the slag site. It can be concluded from the similar chemistries of the groundwater below the site and the groundwater from below the creek bed, and groundwater flow conditions in the vicinity of the creek beds (see Section 3.5.6) that some of the groundwater from the Algoma slag site discharges to West Davignon Diversion.

3.8.3 Location C - Baseline Road Ditch

Six of the seven mini-piezometers located in the Baseline Road ditch were sampled for chemical analyses. Detailed analyses were performed on samples from CBC1-2 and CBC1-3. Limited analyses were performed on the other samples because the mini-piezometers did not yield sufficient water to enable a detailed analysis. All samples were analysed for major anions but only the samples from CBC1-2 and CBC1-3 were analysed for metals and trace organics.

Figure 3.31 illustrates the distribution of chloride, phenols and PAHs at Location C. The chloride concentrations in the groundwater beneath the Baseline Road ditch are approximately one to two orders of magnitude higher than the average chloride concentration at monitoring well A5. The high chloride concentrations beneath Baseline Road ditch shown on this figure are consistent with the presence of a chloride plume in this area shown on Figure 3.23. The source of chloride is likely to be the hydrochloric acid dump. The presence of high chloride concentrations beneath the Baseline Road ditch, but absent to the south at A5, indicates that the shallow groundwater discharges to Baseline Road and does not pass to the north.

The vertical distribution of chloride beneath the ditch is somewhat irregular with higher chloride concentrations generally located at depth. This trend is likely due to infiltration of dilute surface water to the shallow subsurface that occurs seasonally (i.e. spring). Discharge of groundwater to the ditch occurs during other seasons when precipitation and snow melt volumes are low.

The sample from CBC1-3 contained a total BTX concentration of 13 µg/L while the sample from CBC1-2 did not contain detectable BTX. However, the sample from CBC1-2 contained a total PAH concentration of 26.5 µg/L while CBC1-3 contained only 0.5 µg/L chrysene.

3.9 Estimated Mass Fluxes

3.9.1 Basis for Estimation

The flux of dissolved constituents exiting the Algoma slag site has been estimated using the following equation:

$$Q_m = QC$$

where: Q_m = solute mass flux per unit time (M/T),
 Q = volumetric flux (L^3/T), and
 C = solute concentration (M/ L^3).

Unit types are indicated above in parantheses with M, T and L referring to units of mass, time and length respectively.

The mass flux calculations are based on the water volume flux, Q , calculated for the elements shown on Figure 3.20. Concentrations of constituents in the samples from the wells are assumed to be representative of a specified cross-sectional area. Average concentrations along an element flux boundary (Figure 3.20) were determined using an arithmetic weighted average of the average concentrations for wells along that boundary. Detailed mass flux calculations are included in Appendix 9 and summarized in Table 3.21.

3.9.2 Mass Flux Estimates

The mass fluxes of general indicators (chloride, alkali metals) were determined to compare the fluxes via groundwater with the loadings estimated for the on-site creeks (see Chapter 5.0). Mass fluxes were also estimated for trace metals, total cyanide, fluoride, trace organics and nutrients.

The flux of most dissolved constituents is highest directly to the St. Marys River; however, the flux of nitrate, BTX and PAHs is highest to Spring Creek. Spring Creek contributes about 98% of the total dissolved PAH and BTX flux to the St. Marys River.

The mass flux to the Baseline Road ditch is likely to be underestimated as a result of the calculation procedure. The mass flux to the ditch was calculated using chemical data from wells A3, A4 and A5 which were not affected to the same extent that the shallow groundwater beneath the ditch was (affected the mini-piezometer study of the ditch indicated acid-affected groundwater beneath the ditch) because these wells were transgradient (A3, A4) to the area of affected groundwater, or were located across the ditch (A5). Therefore, these wells were not located appropriately to monitor the most affected groundwater discharging to the ditch.

The flux of mass to the West Davignon Diversion is also considered to be underestimated. The flux is assumed to occur through the silty sand till and shallow silty sand -- flux through the unconfined aquifer (bedrock) is not accounted for. The bedrock aquifer is neglected because water quality in this unit appears to be relatively unaffected. The slag fill unit is unsaturated along the diversion, therefore flux through the aquitard is estimated. The slag fill may not be unsaturated along the entire diversion channel and if not, groundwater flux could be much greater to the diversion channel.

The mass flux data are most meaningful when compared with other sources of these constituents to the St. Marys River. This comparison is made in Chapter 6.0.

3.9.3 Potential Mass Flux Resulting from DNAPL Migration

A dense non-aqueous phase liquid or "DNAPL" was identified in the subsurface and in the creek beds during this and previous investigations (CRA, 1988; GLL, 1988) near the former Domtar facility. This tarry material has the potential to migrate in the subsurface as a separate phase. Chemical analysis of this material (see Chapter 5.0) indicates the DNAPL to be comprised of approximately 15% PAHs. The total flux of dissolved PAHs to the St. Marys

River via groundwater was estimated to be about 0.5 kg/day which is equivalent to a tarry DNAPL release of approximately 3.5 litres/day. As described further in Chapter 5.0, 1,000 to 2,000 gallons of tarry material were removed from the creek beds by Algoma personnel as part of a remedial effort. Leakage of even a small percent of this volume to the St. Marys River would constitute a large flux of PAHs to the St. Marys River. Although the flux of dissolved PAHs is high, the potential flux of tarry DNAPL material represents a much greater concern.

4.0 ST. MARYS RIVER SEEPAGE STUDY

4.1 Introduction

The investigation of groundwater seepage to the St. Marys River from the Algoma slag site was undertaken to confirm seepage of groundwater and associated chemical constituents into the river. It was recognized prior to the design of this study that quantifying the total seepage from the site using the methods presented in Section 4.2 would be cost-prohibitive. The seepage study was therefore intended to verify that seepage to the St. Marys River did occur and that the seepage water likely originated from the Algoma slag site. Field work for this study was conducted by Dr. D.L. Lee of Atomic Energy of Canada Limited (AECL). Dr. Lee also aided in the interpretation of the results of the study.

The seepage study was undertaken in several steps.

- A detailed reconnaissance survey was conducted along the river perimeter of the Algoma slag site by towing a sediment probe along the river bed and continuously recording sediment electrical conductance (EC).
- Three areas of elevated sediment EC were instrumented with mini-piezometers during this study. Mini-piezometers installed in an area investigated during previous studies by Dr. Lee were recovered for use during this investigation. The mini-piezometers were used to collect seepage water samples for chemical analyses and to measure water levels from which seepage water flow conditions and hydraulic conductivity were determined.
- Sediment cores for chemical analyses and geologic logging were obtained from two areas with elevated sediment EC.

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- Two areas of elevated sediment EC were instrumented with seepage meters to determine the flux of seepage water through the river sediment to the St. Marys River.

This chapter describes the methods used during the seepage study (Section 4.2) and the results obtained by this study (Sections 4.3 through 4.6). Additional information is also contained in Dr. Lee's report in Appendix 7).

4.2 Methods

The seepage study used techniques developed by Dr. Lee to study the interaction of groundwater and surface water bodies. These techniques are described briefly in the following sections. Details concerning the construction and use of equipment and the application of these techniques are provided in several publications which are referenced in the following sections.

4.2.1 Sediment Conductivity Survey

A survey of sediment electrical conductance (EC) was performed using a continuously-towed sediment probe containing temperature transducers and an EC cell to identify areas of potential groundwater discharge. The probe was drawn along the sediment surface or, in the case of softer sediments, through the sediments, at a rate of about 1 m/s along survey lines parallel to shore at distances offshore of 10, 20, 30, 50, 75 and 100 m. The locations of the survey lines are shown on Figure 4.1. Shoreline reference marks were painted on the shore every 200 m and flagged buoys were placed on the survey lines offshore to aid in relating the recorded data to actual river bed location. Several locations were marked with buoys for further study.

4.2.2 River Bed Mini-Piezometers

Mini-piezometers were installed at Sites A, B and C (Figure 4.1) to depths of 0.75 to 2.8 m using the methods of Welch and Lee (1988). Four mini-piezometers were installed at Site A; however, one was subsequently washed up on shore. Only one mini-piezometer was installed at each of Sites B and C. Site 1 was previously instrumented with eight piezometers (SP-P series) with depths between 1.3 and 2.3 m during the 1987 investigation by Dr. Lee. These mini-piezometers were recovered and tubing brought to shore for use in this study. The integrity of mini-piezometer SP-P46 at Site 1 was questionable because it may have been pulled out during retrieval of the tubing.

Hydraulic conductivities of the shallow river bed sediments at each mini-piezometer were determined using constant head tests (Lee and Cherry, 1978). Hydraulic head measurements were obtained, relative to the river level, using similar methods to those in the creek bed mini-piezometer study (Section 3.2.5).

Water samples from the mini-piezometers were collected immediately after their installation and during some of the groundwater sample collection events. Immediately after installation, water samples were collected from the mini-piezometers using a peristaltic pump for measurement of specific conductance in the field. A water sample could not be obtained from the piezometer at Site C, likely because the screen was located in a low permeability zone. Water samples for laboratory analyses were collected from selected mini-piezometers during all groundwater sampling events except the Winter 1989 event. Ice buildup along the shoreline prevented sampling during the Winter 1989 event. The analytical scheme for the groundwater sampling program described in Section 3.2.4 was also followed for the mini-piezometer sampling. Table 4.1 provides a schedule of mini-piezometer sampling activities and the level of analyses conducted. Table 3.2 lists the detailed analyses for each analytical level.

4.2.3 River Sediment Cores

Two river sediment cores were obtained at Site A and one at Site B using the method of Munch and Killey (1985) modified for manual use from a floating platform. The cores were extruded, photographed, visually logged and packaged into clean glass jars for chemical analysis. Detailed descriptions and photographs of the core are included in Appendix 7.

4.2.4 Seepage Meters

Four seepage meters, 0.152 m^2 in area and 0.6 m in length, were installed manually at each of Sites 1 and A. The volume of water displaced through the meter was measured over time to determine specific discharge to the St. Marys River. Details of the construction and use of seepage meters are given by Lee and Cherry (1978).

4.3 River Bed Hydrostratigraphy

The lithology and hydraulic conductivity of the shallow river bed sediments are described in the following sections.

4.3.1 Lithology

Two river sediment cores were obtained to a maximum depth of 0.80 m at Site A. The top 0.60 m was comprised of red-brown silty sand with slag chunks and gravel. The lower 0.20 m was comprised of red-brown silty sand containing sandstone fragments. These units are lithologically similar to the shallow silty sand unit which underlies the slag at adjacent on-shore boreholes D3 and D4.

One core, extending to a depth of 2.8 m, was obtained at Site B. The top 0.50 m was comprised of black ooze, while the remainder was comprised of dark brown sandy silt and medium- to fine-grained sand. With the exception of the black ooze, which is a recent

deposit, the descriptions of these units are consistent with that of the shallow silty sand observed in on-shore boreholes.

4.3.2 Hydraulic Conductivity

Constant head tests (see Section 4.2.2) were conducted at each mini-piezometer to determine the horizontal hydraulic conductivity of the materials intersected by the mini-piezometer tip. Hydraulic conductivity values were calculated by Dr. Lee and site average values were found to be 6×10^{-5} m/s for Site 1 and 5×10^{-6} m/s for Site A.

4.4 Evidence of Groundwater Seepage

Several lines of evidence indicate groundwater from beneath the Algoma slag site discharges to the St. Marys River. This evidence is described in the following subsections.

4.4.1 Electrical Conductance

Figure 4.1 illustrates the results of the river bottom sediment EC survey. The water from St. Marys River had an EC of 80 μ S/cm, and sediment values were found to have a conductance up to 1,067 μ S/cm. Seven areas, listed in Table 4.2, had significantly elevated EC values. The locations of these offshore anomalies correlates well with the locations of zones of groundwater along the shoreline that exhibited high specific conductance values (Figure 3.22). The correlation of areas of high specific conductance in groundwater beneath the site with adjacent areas of high sediment EC suggests that groundwater discharge from the site may be the cause of the high EC of the sediment. Additionally, the magnitude of the sediment anomalies is similar to the specific conductance of groundwater in on-site areas adjacent to the sediment anomalies which further supports the groundwater discharge hypothesis.

4.4.2 Piezometric Evidence of Local Flow Conditions

Water levels relative to the St. Marys River were measured in the Summer of 1988. Table 4.3 presents the water level measurement results and the vertical gradients calculated from these results. Vertical gradients were upward at all three seepage study sites, indicating discharge of groundwater to the St. Marys River. Vertical gradients at Site A were up to 0.09, 0.05 at Site B, and ranged from 0.017 to 0.14 at Site 1. Vertical gradients at Sites A and B were somewhat higher than those at adjacent onshore locations (monitoring wells D3 and B4, respectively, see Table 3.1). At Site 1, the vertical gradients obtained for the mini-piezometers were an order of magnitude greater than the value measured at piezometer D1, the closest borehole. These results are not surprising in that stronger vertical gradients are expected further offshore where groundwater flow is predominantly vertical.

4.4.3 Seepage Flux

Specific Discharge

Seepage meters were used to measure the specific discharge (volumetric flux per unit area) at Sites A and 1 for comparison to groundwater specific discharge rates. Specific discharge may also be calculated using the Darcy equation:

$$q=ki \tag{4.1}$$

where: q = specific discharge (or Darcy flux) (L/T),
 k = vertical hydraulic conductivity (L/T), and
 i = vertical hydraulic gradient (L/L).

Hydraulic gradient values for the calculation were obtained from mini-piezometer water level measurements (see Table 4.3). Although the vertical hydraulic conductivity is required for

the calculation, the horizontal hydraulic conductivity is used as an estimate of vertical hydraulic conductivity. The constant head tests conducted to determine hydraulic conductivity provide an estimate of horizontal hydraulic conductivity of the geologic material into which the mini-piezometer is installed. It is expected that the vertical hydraulic conductivity could be up to an order of magnitude less than the horizontal value so vertical hydraulic conductivity values were assumed to be one-tenth the horizontal hydraulic conductivity values.

Table 4.4 presents the results of seepage flux measurements at the seepage meters, resulting specific discharge values calculated from the seepage results, and summarizes specific discharge calculations using the Darcy Equation. The estimates of specific discharge using seepage data are generally about one-third the specific discharge values obtained using the Darcy Equation. Although there is a discrepancy between specific discharge values using the two methods, the agreement of the results is still good considering that seepage flux measurements are obtained over a river bottom area of 0.152 m^2 while specific discharge values based on the Darcy Equation are point measurements obtained from a small area beneath the river bottom (i.e. measurements at a small piezometer tip).

Volumetric Water Flux

The off-site volumetric water flux was calculated using groundwater data and discussed in Section 3.5.8. Volumetric water flux for small areas (compared to the entire site perimeter flux calculated in Section 3.5.8) are estimated below to compare with the volumetric water flux calculated using the methods described in Section 3.5.8. The estimation of flux is for small areas instead of the entire site perimeter because the seepage measurements were obtained over a few small areas and are not likely to be representative of the entire site perimeter because of the geologic heterogeneity of the river bed.

Groundwater flux calculations in Section 3.5.8 were for the unconfined aquifer (slag, shallow sand and shallow silty sand units). It is necessary to only consider the flux through the

shallow silty sand unit during this exercise because this is the only unit which was instrumented during the seepage study. Volumetric water fluxes are calculated below for Sites A and 1 for which seepage flux measurements were obtained (see Table 4.4).

Volumetric seepage water fluxes for Sites A and 1 were estimated using the following:

$$Q = q L W \quad (4.2)$$

where: Q = volumetric flow rate (L^3/T),
 q = specific discharge (L/T),
 L = length parallel to shore (L), and
 W = width or distance perpendicular to shore (w).

The average specific discharge from seepage meter data (Table 4.4) was used for each site. A length of 10 m was chosen as this was the approximate length over which the instrumentation was installed. Widths were chosen based on the width of the river sediment EC anomaly: 100 m at Site 1 and 10 m at Site A. Estimated seepage fluxes for these areas are given in Table 4.5.

For comparison, groundwater fluxes through the shallow silty sand were estimated using the following:

$$Q = kiLb \quad (4.3)$$

where: Q = volumetric flux (L^3/T),
 k = horizontal hydraulic conductivity (L/T),
 i = horizontal hydraulic gradient (L/L),
 L = length of the unit parallel to shore (L), and
 b = thickness of unit (L).

The average hydraulic conductivity of the silty sand (see Table 3.6), the average horizontal hydraulic gradient for the western part of the site (see Table 3.13), a length of 10 m (to correspond with the length chosen above) and thickness of the shallow silty sand at monitoring wells D1 and D3 for Sites 1 and A respectively were used in the calculation. The values used in the calculations and resultant volumetric fluxes are provided in Table 4.5.

At both sites, the volumetric flux calculated by seepage water methods are two orders of magnitude larger than the flux calculated using groundwater measurements. This discrepancy is likely due to assuming that specific discharge is homogeneous over a large EC anomaly. This assumption is not valid for the following reason. Figure 4.2, a schematic block diagram, illustrates the relative locations of onshore monitoring wells and offshore seepage meters with respect to groundwater flow. The vertical gradients are greatest near the shore where flow is predominantly vertical. As a result, specific discharge is generally greatest near the shoreline if the hydraulic conductivity remains spatially uniform.

4.5 Sediment and Water Quality

The following two sections summarize results of analyses on river sediment and seepage water samples.

4.5.1 Sediment

The river sediment cores were subdivided into 10 cm (Site A cores) or 25 cm (Site B core) intervals and submitted for chemical analysis. Analytical results are summarized in Table 4.6, while more detailed results are included in Appendix 6. Dredge disposal guidelines are also indicated on Table 4.6 for comparison to the analytical results.

The sediments were mostly comprised of moisture (14 to 51%), iron (0.5 to 14%), calcium (0.1 to 10%) and volatile solids (0.4 to 12%). Manganese, magnesium, aluminum and oil and

grease concentrations were up to 3%, 2%, 1% and 0.6%, respectively. Other major constituents were potassium, sodium, phosphorus, sulphate and TKN. Zinc, lead, chromium, vanadium and PAHs were present in some sediments at concentrations greater than 100 µg/g.

Concentrations of constituents generally decreased with depth for the core obtained from Site B. Notable exceptions to this trend were the anions (bromide, chloride, fluoride and nitrate). The surface sediments (0 to 25 cm) exhibited relatively elevated levels of heavy metals (which exceeded the dredging disposal guidelines) and PAHs (288 µg/g).

Peak concentrations of metals in sediments from Site A were found at depths of 20 to 50 cm. Concentrations generally decreased with increasing depth after this. The dredge disposal guidelines for metals, except zinc and cadmium, were exceeded by metals concentrations in at least one sediment sample. PAH concentrations were about an order of magnitude less than those at Site B (24 to 25 µg/g).

4.5.2 Seepage Water

Groundwater samples for chemical analyses were collected from selected river bed mini-piezometers to confirm the discharge of groundwater from the Algoma Slag Site to the St. Marys River by comparing the chemistry of the groundwater and seepage water samples. Detailed results of the chemical analyses of seepage waters are included in Appendix 6. This subsection summarizes these results and compares these to the chemical results for groundwater samples collected from monitoring wells located adjacent to the seepage sites.

The river bed seepage waters, in general, had specific conductances which were elevated (460 to 4,850 µS/cm) compared to the St. Marys River (80 µS/cm). Seepage water chemistries were consistent with that of the shallow groundwater from the Algoma slag site. The concentrations of most metals were generally low, while anion concentrations were variable. PAHs were detected in seepage water samples from Site A (0.36 to 16.7 µg/L) and Site B

(0.47 µg/L). Only one seepage water sample from Site 1 was tested; this sample did not contain detectable PAHs.

Tables 4.7, 4.8 and 4.9 summarize the seepage water chemistry for Sites A, B and 1 respectively. Also shown are average groundwater quality (i.e. average results based on four sampling events) for samples from adjacent monitoring wells.

At Site A, the seepage water chemistry resembles the average shallow groundwater chemistry for well D4. The river bed seepage water and shallow groundwater samples had similar major ion contents. Trace constituent concentrations (e.g. PAHs, BTX, phenols) were also similar. The shallow groundwater and seepage water chemistries differ from the deep groundwater--major ion contents (e.g. chloride, sulphate) and alkalinity contents differ. The river bed seepage water is chemically similar to the shallow groundwater in the slag unit at this location.

At Site B, the seepage water chemistry is somewhat similar to both shallow and deep groundwater chemistries. The seepage water major ion content is similar to that of the shallow groundwater but pH and specific conductance are similar to the deep groundwater quality.

At Site 1, the differences between shallow and deep groundwater quality are not substantial (Table 4.9). The seepage water chemistry is similar to both groundwater types.

The similarity of the river bed seepage water chemistry and on-site shallow groundwater chemistry, in addition to demonstrated discharge of groundwater to the St. Marys River, confirms the discharge of shallow groundwater from the Algoma Slag Site to the St. Marys River.

4.6 Estimated Mass Fluxes

A comprehensive evaluation of mass flux to the St. Marys River based on groundwater data was provided in Section 3.3.9. The mass flux estimates in this section are provided to confirm the estimates based on groundwater data.

Mass flux for seepage Sites A and 1 were estimated using average values of seepage water chemistry and the volumetric water fluxes calculated in Section 4.4. These estimations assume that little or no change in chemistry occurs during the upward flow of seepage water to the river. Mass flux is, therefore, equal to volumetric water flux times concentration.

Table 4.10 summarizes the mass flux calculations for the two seepage study sites for which volumetric water fluxes were calculated (see Section 4.4). Mass fluxes were calculated for selected dissolved constituents only (chloride, sulphate, phenols and PAHs) for comparison to mass flux based on groundwater data. Concentration values used in the calculation were seepage site average concentrations. Mass flux is presented in units of total site mass rate per year and mass rate per year per unit area.

The mass fluxes presented on Table 4.10 are presented in Table 4.11 for comparison with mass fluxes calculated from groundwater data. The chloride, sulphate and phenols fluxes measured at the seepage sites are about 3 to 5% of the estimated mass flux to the St. Marys River along the site shoreline via groundwater. The PAH flux is less than 0.001% of the flux identified for groundwater. These two small areas selected for seepage study are estimated to contribute about 5% of the total mass flux for some chemical constituents. It is not improbable, therefore, that the seepage along the remaining shoreline accounts for the other 95% of the total estimated flux of constituents. The seepage study results confirm the reasonableness of the mass flux estimates for the shoreline.

5.0 SURFACE WATER STUDY

5.1 Introduction

The surface water component of the Algoma slag site study focused on quantification of surface water quantity and quality at the Algoma slag site. The surface water study was designed and implemented to determine the flux of dissolved constituents to St. Marys River originating from on-site sources. To accomplish this several monitoring techniques were employed. These are outlined below:

- surface infiltration measurements were conducted throughout the slag site to measure hydraulic conductivities and to determine runoff patterns.
- a standard volumetric rain gauge was established on-site to monitor precipitation on a bi-weekly basis.
- surface water flow and water quality stations were established at the outlets of all creeks originating on-site. Additionally, all creeks originating upstream of the Algoma site and receiving discharge from the site were monitored. These creeks were monitored at the point where they intersect the Algoma slag site (upstream) and at the discharge areas to St. Marys River (downstream).
- two flow monitoring stations had continuous water level recording instruments installed and operated during non-winter months.
- flow velocity measurements were conducted at selected surface water monitoring stations for the purpose of developing stage discharge curves.

Water quality samples were collected on a monthly basis (excluding winter months) at 5 of the surface water stations. The water quality information along with the water quantity data

collected at the Algoma site were used to calculate the flux (loading) of dissolved constituents to St. Marys River. The following sections of this chapter provide details of methods employed during the investigation, results of flow monitoring and water quality sampling, and determination of loads of dissolved constituents.

5.2 Study Purpose and Objectives

The primary purpose of the surface water component of the Algoma slag site investigation was to determine the magnitude of dissolved load transport from the on-site creeks to receiving water bodies. The objectives of the surface water study were to:

- quantify surface water flow volumes originating from the Algoma slag site on a semi-continuous and monthly basis for a period of approximately one year,
- quantify surface water flow volumes from upstream of the slag site within the Algoma slag site watersheds,
- collect surface water quality data at selected sites on a monthly basis during ice-free periods, and
- determine mass flux and mass balance estimates of various dissolved chemical constituents originating from the site.

5.3 Methods

The following subsections describe the data collection and data analysis methods used during this study.

5.3.1 Meteorological Monitoring

Meteorological monitoring for this study included monitoring parameters which directly influence runoff and water balance, namely, precipitation rate and volume and air temperature. The precipitation rate information was needed to determine the flow balance and hydrologic

yield for the watersheds that drain the Algoma slag site. The air temperature data was used to determine when periods of freezing were encountered and to compare with the water temperature data.

The Algoma slag site is located between two Environment Canada Atmospheric Environment Service (AES) stations which are in close proximity (Figure 5.1). The Sault Ste. Marie Airport Station is located 9 km to the west southwest of the Algoma slag site. Sault Ste. Marie Station #2 is located approximately 5 km to the northeast. Given the close proximity of these two stations to the site, the meteorological monitoring conducted at the Algoma slag site was limited to volumetric total rainfall for non-winter months. All other meteorological data required for the study was acquired from AES for these two stations.

An AES standard volumetric rain gauge was established at station SW5 shown in Figure 5.2. The standard volumetric rain gauge consisted of a plastic cylindrical gauge of 10.0 cm in diameter. The rain gauge was used to manually record depth of rainfall over a given monitoring period and was monitored approximately every two weeks.

Other meteorologic data including precipitation volumes and rates and air temperature information was obtained for the study from the two AES stations referred to above. Hourly and monthly average data was obtained for the time period of the study. The hourly data were used to compare precipitation totals for the periods of precipitation recorded at the site. The monthly data were used to determine the flow balance for the months which were monitored at the site. The temperature data from the two AES stations were used to verify both the air and water temperatures observed at the site.

5.3.2 Hydrologic Monitoring

Hydrologic monitoring methods used for the surface water study were measurements of surface infiltration, measurement of stream flow, and preparation of a stage-discharge curve. These methods are described below.

Surface Infiltration Measurements

A monitoring program was designed following inspection of the site in June 1988. Surface infiltration measurements were conducted across the site at that time to determine surface material hydraulic properties (hydraulic conductivity). The purpose of these measurements was to determine if any of the site surface would produce overland runoff to receiving waterways. The study area was divided into regions of roughly homogeneous surface and shallow subsurface material properties which would have different rates of infiltration of water into the ground. Most of the site surface consisted of medium to very coarse slag material, therefore surface infiltration measurements were made in regions characterized by similar surface materials and similar land use (i.e. slag disposal areas, sand disposal areas, oil sprayed zones and storage compounds etc.).

Initially, the Guelph Permeameter (constant head well permeameter - see Reynolds and Elrick, 1986) was employed to obtain infiltration measurements. However, the conditions found at the site proved to be unsuitable for this method because stable well conditions required for the measurements could not be established.

An adaptation of the percolation (septic system) method (Ontario Ministry of the Environment, 1982) was used to determine the relative infiltration rates for the surface materials. This method was adapted for the Algoma slag site and was the only suitable means of obtaining infiltration estimates given the site conditions. The method used differs from the Guelph Permeameter method in that it is a falling head test rather than a constant head test. A 9.5 cm shallow cylindrical apparatus was placed into the slag to a depth of approximately 2 cm. The cylinder operates as would the sidewalls of a well permeameter and similar to the Guelph Infiltrometer (Baumgartner, *et al.*, 1987). Water was poured into the reservoir of the cylinder to a datum level and then allowed to infiltrate into the slag material. The time to completely drain the reservoir was recorded. This procedure was repeated several times until a reasonable steady state was obtained (i.e. infiltration times were equal). Infiltration estimates provided

by this method are considered better than order of magnitude estimates in the slag-covered site areas and are within the theoretical range for the sand areas.

Stream Flow Monitoring

Surface water courses draining the Algoma slag site were instrumented with flow monitoring devices. Surface water monitoring stations were established on all major water courses both upstream and downstream of the site. Monitoring stations were established at the mouths of creeks originating on site. The locations of the five flow monitoring stations established are shown in Figure 5.2. Two major surface water courses, Baseline Road Ditch and Spring Creek, originate on-site (Figure 5.2). Two other major water courses, West Davignon Diversion and Bennett Creek, originate upstream but flow adjacent to the Algoma slag site and are shown on Figure 5.2. Monitoring stations were established on the West Davignon Diversion at its mouth near St. Marys River (station SW1) and at station SW2 approximately 75 metres upstream of Baseline Road. Station SW3 was installed on Bennett Creek just upstream from the mouth of Baseline Road Ditch. Station SW4 was established at the outlet of Spring Creek which consisted of a culvert draining into Bennett Creek. Bennett Creek flows into a vessel slip located at the boundary between the site and the Algoma steel-making facility on the east side of the Algoma slag site.

Stream flow instrumentation consisted of staff gauges and continuous water level monitoring devices. All five of the monitoring stations had staff gauges installed while stations SW1 and SW5 had Stevens A type continuous water level recorders. Table 5.1 contains a list of hydrologic monitoring equipment installed at the surface water monitoring stations.

A flow control structure was installed at station SW1 (West Davignon Diversion at St. Marys River). A rectangular weir with an 0.6 m x 0.15 m notch constructed from wood and concrete blocks and back filled with native sediment. was established in August 1988. The weir's total length was 3.35 metres and was installed at a small natural channel constriction approximately

3 metres upstream from the point where the channel drops about one metre to the St. Marys River. Refer to Figure 5.3 for a sketch of the weir at SW1.

Ice during the winter and high flows from the spring melt damaged the weir at SW1. Subsequently, the weir was re-installed on May 11, 1990 following the subsidence of high flows in the West Davignon Diversion.

Pre-existing hydraulic control sections existed at all other surface water monitoring stations. Station SW5 had a control section which consisted of two 18 inch concrete culverts, while station SW4 had one galvanized metal 18 inch culvert. The monitoring stations SW2 and SW3 were located at suitable channel segments, where flow velocity measurements could be taken.

Flow velocity measurements were taken at all sites where flow hydrographs were to be developed. Flow velocities were determined under different flow regimes to produce stage-discharge curves for these sites. The standard velocity-area method was used to determine flow rates in all open channel sampling stations (SW1, SW2, SW3, SW5). The standard velocity-area method involves partitioning the channel's cross section into segments and then measuring the area and velocity of each segment (Kirkpatrick and Shelley, 1975; Kulin *et. al.*, 1975). A flow is calculated for each discrete segment and all segment flows are summed to produce a total channel flow estimate.

Flow velocity was measured using a Montedoro-Whitney PVM-2A portable velocity meter which has a manufacturer rated accuracy of plus or minus 1 percent. At station SW4, flow was determined by collecting flow through the discharge culvert and noting the time to obtain a standard volume.

Flow velocity measurements were obtained four times for each of the surface water monitoring stations, except SW4, at which velocity was measured three times. The flow rate data was then used to produce stage-discharge curves for stations SW1 through SW5. Water levels

were recorded at all flow monitoring stations monthly during ice-free periods for the purpose of determining flow rates at those times.

Stage-Discharge Curve for SW-1

A stage-discharge (or rating) curve for the SW-1 station was established based on a simple hydraulic analysis of the control structure. As depicted in Figure 5.3, the geometry of the SW-1 control structure represents a compound weir with a 0.6 m rectangular notch set in the centre of a 3.35 m wide weir. The rating curve for this structure can be represented by theoretical weir equations that apply within certain water level ranges.

In general, the discharge over a weir structure is described by an equation of the form (see Chow, 1959):

$$Q = C_w LH^{1.5} \quad (5.1)$$

where Q is the discharge (m^3/s),
 L is the length of the weir (m)
 H is the water level head (m)
 C_w is a discharge coefficient.

For large weirs with low approach velocities, $C_w=1.84$, but for smaller weirs, the discharge coefficient varies and is a function of the head, H . Moreover, end contractions on the weir reduce the effective width of the weir. The weir coefficient can be determined from field observations if there are sufficient flow velocity measurements to establish a trend. However, empirical relationships for the weir coefficient are available in most standard hydraulic text books (e.g. Chow, 1959; Streeter and Wylie, 1981).

For the SW-1 weir, the rating curve is represented by the following three equations.

$$Q = (0.02 + 12.2 H) H^{1.5} \text{ for } 0 \leq H \leq 0.1078 \text{ m} \quad (5.2)$$

$$Q = Q_1 = (2.07 + 1.78H) (0.6096 - 0.2H)H^{1.5} \text{ for } 0.1078 < H \leq 0.1524 \text{ m} \quad (5.3)$$

$$Q = Q_1 + Q_2 \text{ for } H > 0.1524 \text{ m} \quad (5.4)$$

with $Q_2 = 6.16 (H - 0.1524)^{1.5}$, and Q_1 from Eq. (5.3).

where: Q = flow in m^3/s

H = hydraulic head measured in metres

A comparison of the predictions from Eq. (5.2) to (5.4) with the available flow velocity measurements is presented in Table 5.2. In general, the agreement is quite good and typical for this type of weir installation (Marsalek, 1976).

5.3.3 Water Quality Sampling

Monitoring Stations and Sample Collection

Surface water quality sampling stations were established at nine locations near and throughout the Algoma slag site. In addition to the five surface water stations described in Section 5.3.3 (SW1 to SW5), four other stations were monitored during the study. Station SW6, located on Spring Creek, was selected for its proximity to the Domtar site and the upstream extent of Spring Creek. SW7 was located at the upstream part of Bennett Creek as it enters the most northerly portion of the Algoma slag site. SW8 and SW9 were established on Bennett Creek at the Baseline Road Bridge and the Bennett Creek mouth, respectively. The locations of all stations are shown in Figure 5.2. The surface water monitoring stations were established for

the monitoring of water quality on a monthly basis (samples were collected only when weather and flow conditions permitted).

Surface water samples were collected using a depth-integration technique to obtain a representative water column sample. A number of different types of sample containers were used to collect the water samples from each station because many chemical parameters were analysed for. Plastic bottles were used for inorganic constituents and glass bottles for organic parameters. Field measurements of water temperature, pH, specific conductance, dissolved oxygen and water levels were recorded at the time of water sampling. The average of at least three measurements of pH, specific conductance, and dissolved oxygen were recorded for each sampling event at each station.

Analytical Program

Surface water quality sampling began in August 1988. Surface water samples were collected from stations SW1 through to SW7. At this time there were three levels of surface water sampling. The three surface water sampling levels were as follows.

- Level 1: field pH and specific conductance, oil and grease, dissolved organic carbon (DOC including volatiles), trace metals (DCP 9 element scan - Cd, Cr, Co, Cu, Fe, Pb, Mn, Zn, Ni), anions and total phenols.
- Level 2: field pH and specific conductance, volatile organic compounds (VOCs), polyaromatic hydrocarbons (PAHs), cations/metals, anions, sulphide, alkalinity, TKN, DOC and dissolved inorganic carbon (DIC).
- Level 3: level 2 parameters plus nitrate, ammonia, total cyanide, arsenic, selenium, mercury, total phosphorus (TP), and phenol species.

During the fall of 1988 the sampling continued using the above sampling plan. Stations SW1 to SW5 were sampled monthly with samples collected from SW6 to SW9 occasionally to provide background data.

Upon review of the Fall 1988 sampling results, the surface water monitoring levels were changed to streamline the program toward constituents of environmental concern. The 1988 data indicated that several of the parameters associated with Levels 2 and 3 were found to be below detection limits for most of the monitoring stations. Consequently, a two level system was adopted during 1989. The two level system consisted of:

- Level 1: Field pH and specific conductance, anions, alkalinity, TKN, DOC, TP, total phenols and the alkali metals.
- Level 2: Level 1 parameters plus PAH, 19 element metal scan and total cyanide.

The two level system was used for the remainder of the study.

The sampling levels are identified in this section and all tables of analytical data state the sample level associated with the date of sampling.

5.3.4 Flow and Mass Balance Determination

Flow balance calculations involve the estimation of surface water volume inflows and outflows for the Algoma slag site. The flow balance described here includes all surface water contributions from the various areas of the slag site and accounts for precipitation as input, runoff to surface streams, and contributions to and from groundwater to the St. Marys River. The mass balance accounts for any mass contributions from areas upstream of the site.

Flow data from nearby stations was obtained from the Sault Ste. Marie Region Conservation Authority and Water Survey of Canada (Environment Canada) published data to provide for a means of comparison with surface water monitoring conducted at the Algoma slag site. Conservation Authority and topographic maps were obtained for the purpose of delineating the upstream watershed boundaries. The monthly data provides estimates for the relative flow contributions of each sub-basin area. The mass balance relationships for the distinct sub-basins was based upon the data collected over the 12 month sampling period. Mass flux or loading estimates for each station were determined from the product of the mean annual daily flow and the statistical mean concentration. Statistical mean concentrations were determined from at least three water samples. However, in a certain limited number of cases, loads were computed with statistical mean concentrations of only two water samples. More information regarding flow and mass estimates is given in Sections 5.7 and 5.10.

5.4 Region Drainage System

The Algoma slag site is located on the north shore of St. Marys River and is bounded by Leigh Bay of St. Marys River to the west, Algoma steel making facility to east and the City of Sault Ste. Marie to the north.

Three major watersheds (Leigh Bay Creek, Bennett Creek, West Davignon Creek) contribute flow to two water courses (Bennett Creek and West Davignon Diversion) which flow adjacent to the Algoma slag site (Figure 5.1). Bennett Creek flows on the east side of the site adjacent to city property discharges into a vessel slip between the Algoma steel making facility and coal/coke storage area and eventually discharges to St. Marys River. The West Davignon Diversion flows along the west side of the site (Figure 5.2).

Bennett Creek watershed is the largest (23.6 km^2) of the three watersheds in the study area. The West Davignon Creek Watershed surface area is 16.3 km^2 while the Leigh Bay Watershed area is approximately half of West Davignon's (8.5 km^2). During low flow

periods, West Davignon Creek flows into Bennett Creek just upstream of the Algoma slag site. Leigh Bay Creek flows into the West Davignon Diversion.

During high flows, flow from both Bennett Creek (greater than $1.60 \text{ m}^3/\text{s}$) and West Davignon Creek (greater than $1.35 \text{ m}^3 \text{ s}^{-1}$) are diverted into the West Davignon Diversion through an engineered diversion channel. The diversion was designed to operate during periods of high flow to minimize flood damage in the western portion of Sault Ste. Marie. Water is routed to the West Davignon Diversion when water levels in these creeks reach a design maximum. Flow in Bennett Creek downstream of the diversion point will have a theoretical maximum flow of approximately 2.95 to $3.10 \text{ m}^3/\text{s}$ during the high flow periods due to the design of the diversion systems. Base flow at the diversion points on Bennett Creek and West Davignon Creek normally flows through large culverts through to their normal drainage route.

5.5 Meteorology

Temperature Summary

The average monthly air temperatures during the surface water monitoring period, August 1988 to July 1989, are summarized in Table 5.3. For comparison with long-term values for the region, the 1951-80 normal values for both AES Stations (Sault Ste. Marie Airport and Station #2) are provided. Corresponding histogram plots of the data in Table 5.3 are presented in Figures 5.4 and 5.5.

In general, similarities exist between the 1988-89 data and the long-term normals for the region. The Sault Ste. Marie Station #2, located in the centre of the City, is normally about 0.4°C warmer than the Airport weather station.

During the surface water monitoring period, air temperatures were close to the long-term normal. At the start of the period (August and September 1988), the temperatures were

warmer than normal (up to 1.7 C° warmer). Later in the fall, temperatures were about 2 C° cooler for October, and 2 C° warmer than normal for November. During the winter months, December was close to normal, January was about 3 C° warmer, and February and March were about 2 C° cooler than normal. The spring and early summer months were about one degree warmer than normal.

Precipitation Data Summary

Table 5.4 summarizes the precipitation amounts measured at the Algoma slag site (SW-5), and observations made at the two neighbouring AES stations during the monitoring period. In general, the total precipitation measured at the SW-5 rain gauge was about 85% of total recorded at Sault Ste. Marie Airport, and 82% of the total for the Sault Ste. Marie Station #2 gauge. The relationship between precipitation amounts measured at the SW-5 rain gauge and the AES stations remained constant throughout the monitoring period. Discrepancies between AES and the site data may be due to undercatch (common in small standard gauges) and spatial variability in precipitation volumes. The precipitation records at the neighbouring AES stations are assumed to be representative of the precipitation amounts received at the Algoma slag site.

The monthly precipitation amounts for the study period (August 1988 to July 1989) are summarized in Table 5.5, together with the long-term normal values. This table lists the number of days in which precipitation occurs for each month as well. Graphs corresponding to the amounts listed in Table 5.5 are shown in Figures 5.6 and 5.7.

In general, the total precipitation for the study period was above the long term normal, particularly at the Sault Ste. Marie Station #2 where it was 15% above normal. The differences in the monthly amounts at each station are indicative of the spatial variability in the rain and snowfall events that occur in the region. The late summer and fall periods of 1988 were extremely wet, with precipitation well above normal at both stations. In particular, precipitation amounts for October and November were about 75% to 100% above average.

With the exception of March at Sault Ste. Marie Station #2, the precipitation amounts during the winter and spring months were below normal (typically 80% of normal). Extremely dry conditions existed for July 1989, where the monthly totals at both AES climate stations were only 15% of their normal values.

5.6 Surface Infiltration and Runoff Patterns

Infiltration measurements were performed on 11 different areas of the Algoma slag site in June 1988 (Figure 5.2). The results of infiltration measurements are summarized in Table 5.6. All of the sites had infiltration rates which ranged between approximately 10^{-1} and 10^{-2} cm/s. This rapid to extremely rapid infiltration is characteristic of very coarse-grained materials. Infiltration rates for sandy soils typically range from 10^{-3} to 10^{-4} cm/s, therefore, the slag material is hydraulically more like gravel than a soil. The rapid to extremely rapid infiltration rates are characteristic of approximately 80 to 85% of the surface area of the site. This area is not expected to produce surface runoff.

Areas with lower infiltration rates include the filter cake, central lime and pickling liquor disposal areas. Several of the oil-sprayed areas showed signs of surface cracking at the time of infiltration measurement. The high infiltration rates shown in Table 5.6 in the oil sprayed areas is the result of the surface cracking phenomenon. However, infiltration rates at these sites will decrease dramatically immediately after oil spraying. During heavy rainfall or snowmelt periods, these sites may produce surface runoff. Runoff from the oil-sprayed areas will not migrate far as most of these areas are surrounded by areas of extremely high infiltration rates, it is not expected that any surface runoff will reach streams or surface water courses by direct overland flow.

Based upon the findings of the surface infiltration measurements, it is unlikely that runoff will occur. The possibility exists that some runoff may occur during the winter months when the surface slag is frozen. This has not been verified by field observations. It is expected that this would be an insignificant pathway for pollutant transport if these frozen conditions did

exist. Therefore, virtually all precipitation falling on the Algoma slag site, except for that which evaporates, will infiltrate through the surface and be incorporated into the groundwater. There are internal areas (oiled roads, etc.) which may produce some runoff, however, these areas are very small compared to the overall site. As most of the slag site has a surface infiltration rate in the range of 10^{-1} to 10^{-2} cm/s, even extreme rainfall (for example, a one-in-100 year storm) would be assimilated as infiltration without producing surface runoff.

5.7 Monthly Streamflow Estimates

Estimates of streamflow at each monitoring site were required to develop mass flux estimates. However, because continuous streamflow records are not available at all sites for the entire study period, it was necessary to develop discharge estimates for each surface water station using data available from neighbouring stream gauges maintained by the Water Survey of Canada (WSC).

Time-series plots of measured flows at SW1 and SW5, and two WSC gauges on the nearby Big Carp and Root Rivers (see Figure 5.1) are given in Figures 5.8 and 5.9 for the periods August to December 1988, and May to July 1989, respectively. These time-series plots indicate that the flow patterns at the WSC gauges are similar to those of the SW1 station--there tends to be a correspondence of most of the flow peaks at SW1 with those of the Big Carp and Root Rivers. The SW1 curve is in closer agreement at high flows with the Big Carp River curve, because the diversions on West Davignon and Bennett Creeks direct flow to the West Davignon Diversion. Under this condition, the drainage area at SW1 is about equal to the contributing area at the Big Carp gauge. The SW5 flows tend to follow the baseflow pattern set by the "flow troughs" in the Big Carp and Root River curves. Consequently, it is possible to develop estimates of SW1, SW2 and SW3 flows using a fitted relationship between the observed SW1, SW2 and SW3 flows and the corresponding Big Carp River flows, the closest available WSC gauge to the study area.

Appendix 10 provides a comparison of the observed flow data at each monitoring station with the corresponding daily flow data for Big Carp River for each sampling day. These data were used to establish relationships between the Big Carp River flows and those at the monitoring stations. Measured flows at the SW1 station were quite variable, possibly due to seepage through the channel bed upstream and adjacent to the weir. SW1 flows should always be higher than the SW2 flows because the SW1 site is downstream of the SW2 station. This was not observed, and instead the downstream SW1 flows were generally lower than upstream at SW2. The SW1 data was used to estimate the times of high flow events. The flow at SW1 was estimated by prorating flow rates at SW2 and the Big Carp sites.

Power-law relationships were fitted to the SW2 and SW3 observed data using the corresponding Big Carp River daily flow as the predictor value. For SW2, any flows that were believed to be influenced by the upstream diversions (usually during severe events and spring snowmelt), were not included in the development of the relationships. From discussions with a staff member at the Sault Ste. Marie Region Conservation Authority, it was found that when the flow at SW2 exceeded $2.95 \text{ m}^3/\text{s}$, the diversions on Bennett and West Davignon Creeks would be operative. At this level, the drainage areas at the SW1 and SW2 stations are about equal to that upstream of the Big Carp River gauge, and so the SW2 discharge can be taken directly from the Big Carp River records. As a conservative estimate, the SW1 flows were set equal to the SW2 flows.

The fitted flow relationships are as follows:

$$Q_{\text{SW2}} = 0.325 (Q_{\text{BC}})^{1.5469} \quad \text{for } Q_{\text{BC}} < 4.16$$

[5.41]

$$Q_{\text{SW2}} = Q_{\text{BC}} \quad \text{for } Q_{\text{BC}} \geq 4.16$$

$$Q_{\text{SW3}} = 0.339 (Q_{\text{BC}})^{0.6299}$$

[5.42]

$$[5.43] \quad Q_{SW1} = Q_{SW2}$$

where Q_{BC} denotes the flow at the Big Carp River gauge, and Q_{SW1} , Q_{SW2} and Q_{SW3} represent the discharges at stations SW1, SW2 and SW3, respectively. Here, all discharges are expressed in m^3/s .

Published average daily flow values for the Big Carp River Equations [5.41] to [5.43] were used to compute the daily discharges for the SW1, SW2 and SW3 stations. The results of these computations are summarized in Appendix 10, and presented graphically in Figures 5.10 to 5.13.

For both SW1 and SW2, April 1989 had the highest total flow volume of any month during the period of study, followed closely by November 1988, then October 1988, and March 1989. These four months accounted for about 89% of the total flow volume for the entire study period. The lowest total volume of any month was July 1989. The maximum daily flow of $13.3 m^3/s$ at SW1 and SW2 occurred on November 6, 1988, whereas the minimum daily flow of $0.0007 m^3/s$ occurred five times in July 1989. Total mean daily flow for the study period SW1 and SW2 was $58,400 m^3/d$, while total yearly flow was $21,300,000 m^3/year$. Baseline Road Ditch (SW5) and Spring Creek (SW4) had the lowest flows measured at the site. Estimated mean daily flows at these stations were $88.6 m^3/d$ (SW4) and $339 m^3/d$. Total yearly flows were $32,300 m^3/year$ and $124,000 m^3/year$ for SW4 and SW5 respectively.

The diversion on Bennett Creek limits the large and infrequent flows from appearing at the SW3 station and therefore its flow pattern is relatively steady. The four highest flow months were November, October and December 1988, and April 1989. These months account for 62% of the total flow for the period of record. As with SW1 and SW2, July 1989 had the lowest total flow volume of any month for SW3. The maximum daily flow at SW3 of $1.73 m^3/s$ occurred on November 6, 1988, and a minimum daily flow of $0.027 m^3/s$ occurred on July 25, 1989. The total flow volume for SW3 was about 45% of the totals for SW1 and SW2.

5.8 Water Quality

Surface water chemical data for each surface water monitoring station are listed in Appendix 11. Reference information also listed are sample date, analytical reference number and sampling level. The results of the surface water quality monitoring have been organized into the following groups of parameters to facilitate discussion:

- i) field measurements,
- ii) anions/cations and nutrients,
- iii) organic compounds, and
- iv) metals.

5.8.1 Field Measurements

Field measurements of water temperature, pH, and specific conductance collected at the time of sampling are shown in Table 5.7. Dissolved oxygen concentration measurements were also collected on four occasions and are included in Table 5.7.

Temperature

Water temperature was measured at the time of sampling to compare with both air temperature and groundwater temperature. The water temperature data for all sites followed the same general trend or annual pattern as the air temperature with a time lag. Generally, water temperature at the stations near the Domtar Facility (SW4, SW6) and the Baseline Ditch Road (SW5) were consistently 1-2 C° higher than those at the West Davignon Diversion sites (SW1 and SW2) with the exception of August 1988. Groundwater is the major source of water to these channels, which likely moderates the water temperature.

pH

Measurements of pH recorded at the site ranged from a minimum of 6.5 at SW1 (April 11 and May 12, 1989) to 12.5 at SW5 (May 12, 1989). The West Davignon Diversion had an average pH (averaged over the sampling period) just slightly above neutral with SW1 and SW2 having an average pH of 7.2 and 7.6, respectively. Stations SW3 and SW4 were slightly basic with average pH values of 8.3 and 8.6, respectively. Station SW5 had the highest pH average of 11.4 while SW6 had an average of 9.7 (based on 3 measurements only). Variability was relatively small with standard deviations ranging from 0.47 (pH units) to 1.4 and where there were more than 6 measurements the greatest standard deviation was 1.0 (pH units).

Dissolved Oxygen

Dissolved oxygen levels ranged from 4.5 mg/L (SW6) in August to 16.4 mg/L at SW1 in April (during the spring melt period when water temperature was very cold). The 16.4 mg/L value is probably an over estimate because oxygen saturation at 0°C is approximately 14 to 15 mg/L depending on barometric pressure. Mean dissolved oxygen concentrations were identical for SW1 and SW2 (11.4 mg/L); however, the range was larger at the SW1 site (8.0 to 16.4 mg/L) compared with SW2 (8.4 to 14.8 mg/L). Station SW3 also had a high mean dissolved oxygen concentration of 11.3 mg/L and a range of 8.1 to 13.2 mg/L.

Dissolved oxygen concentrations from stations SW4, SW5 and SW6 were all lower compared with SW1, SW2 and SW3. Water tested at station SW4 had a mean dissolved oxygen concentration of 7.9 mg/L and a range of 6.4 to 8.8 mg/L. Water from station SW5 had a mean dissolved oxygen concentration (6.7 mg/L) slightly lower than SW4 at 7.9 mg/L. Two dissolved oxygen readings at SW6 were both very low (4.1 and 4.5 mg/L).

Specific Conductance

Overall, specific conductance (SC) ranged from a low of 45 $\mu\text{S}/\text{cm}$ at SW2 (December 2, 1988) to 11,200 $\mu\text{S}/\text{cm}$ at SW5 (June 16, 1989). All SC data exhibit the characteristic yearly trend (positive temperature relationship): each station had maximum SC values when water temperatures were high and minimum values occurred when water temperature were at their lowest measured values (in April).

Station SW2 had the lowest mean SC (79 $\mu\text{S}/\text{cm}$) of all stations tested and the lowest range (45 to 171 $\mu\text{S}/\text{cm}$). Water samples from stations SW1 and SW3 were similar with mean SC values of 135 and 133 $\mu\text{S}/\text{cm}$ respectively. Ranges were also very similar with a range of 80 to 321 $\mu\text{S}/\text{cm}$ for SW1 and a range of 69 to 337 $\mu\text{S}/\text{cm}$ for SW3. The SC values at SW1 were consistently higher (33 to 94%) than those measured at SW2 which may indicate input of dissolved constituents from the Algoma slag site adjacent to the diversion channel.

Stations SW4, SW5 and SW6 all had very high SC values. SW4 had a range in SC values of 1,760 to 4,220 $\mu\text{S}/\text{cm}$ and a mean of 2,813 $\mu\text{S}/\text{cm}$. Station SW6 on Spring Creek consistently had higher readings than its downstream station (SW4). Station SW5 (Baseline Road ditch) had the highest SC values of all monitoring stations. The mean SC reading at this station was 5,624 $\mu\text{S}/\text{cm}$ with a range from 3,350 to 11,200 $\mu\text{S}/\text{cm}$. Station SW5 is also the site that had the highest ion concentration - particularly chloride. The source of all flow in this ditch appears to be seepage from the slag pile to the south. This could account for the elevated SC of the surface water.

5.8.2 Anions, Cations and Nutrients

This group of water quality parameters consists of DIC, alkalinity, total cyanide (TC), bromide (Br), chloride (Cl), fluoride (F), sulphate (SO_4), sulphide, ammonia (NH_3), nitrate (NO_3), total kjeldahl nitrogen (TKN) and total phosphorus (TP). Summary statistics including mean,

median, standard deviation, maximum and minimum were determined for all water quality parameters and are found in Appendix 12. For the purpose of reporting and clarity of presentation, only parameters which have sufficient data to produce statistical summaries will be discussed. For this reason, discussion will focus on Cl, Br, SO₄, TKN and TP. There is insufficient (several non-detected values) data to produce reliable loading estimates for DIC, sulphide, total cyanide, bromide and fluoride.

Chloride and Sulphate

Chloride concentrations ranged from a minimum of 4.5 mg/L at SW2 (December 2, 1988) to a maximum of 4,100 mg/L at SW5 (June 16, 1989). Stations on the West Davignon Diversion (SW1, SW2) generally had lower Cl concentrations (SW1: 6.0 to 18.2 mg/L; SW2: 4.5 to 13.8 mg/L) compared with the stations on the east side of the site (SW4: 270 to 1,460 mg/L; SW5: 1,200 to 4,100 mg/L; SW6: 700 to 2,200 mg/L).

Single water samples collected downstream of the outfall of Baseline Road Ditch (SW8) and Spring Creek on Bennett (SW9) had slightly elevated Cl levels compared with samples collected at SW3 (upstream) indicating that there was significant flow in Bennett Creek to dilute the flow from the two outfalls at SW4 (Spring Creek) and SW5 (Baseline Road ditch).

The sulphate (SO₄) concentration range was lower than the Cl, but still considerable when examining samples collected from all of the surface water monitoring sites. Sulphate concentrations ranged from 5.65 mg/L at station SW2 to 640 mg/L at SW5.

Nutrients

Selected surface water samples were analysed for nutrients (nitrate-N, TKN and total phosphorus). Nitrate-N concentrations ranged from 0.04 mg/L at SW1 to 2.5 mg/L at SW6. The mean nitrate-N concentration for the study period followed the same general trends as Cl

and SO_4 with SW1 (0.188 mg/L) and SW2 (0.182 mg/L) having lower mean concentrations than SW3 (0.314 mg/L), SW4 (0.183 mg/L) and SW5 (0.350 mg/L). TKN concentrations ranged from 0.220 mg/L (SW3) to 5.80 mg/L (SW5). As with nitrate-N, the highest TKN concentrations were found at stations SW4 (3.5 mg/L, June 16, 1989) and SW5 (up to 5.8 mg/L). Stations SW1, SW2 and SW3 had comparable mean concentrations.

Total phosphorus concentrations ranged from 0.002 mg/L at SW4 to 0.088 mg/L also at SW4. Total phosphorus concentrations did not exhibit the same general trends as did the nitrogen compounds. Although mean total phosphorus concentrations were comparable at SW1, SW2, and SW3 (0.009 to 0.012 mg/L), SW4 had the highest mean TP concentration (0.023 mg/L) while SW5 had the lowest mean concentration (0.0064 mg/L). Only one sample (0.088 mg/L) collected in April 1989 at SW4 exceeded the Provincial Water Quality Objective (PWQO) of 0.030 mg/L.

5.8.3 Organic Compounds

Surface water samples were analysed for DOC, phenols, PCBs, VOCs, BTX, oil and grease and PAHs.

PCBs and Oil and Grease

Only one surface water sample (SW1 in August 1988) was analysed for PCBs. This sample had a non-detected total PCB concentration (less than 0.10 $\mu\text{g/L}$). Oil and grease concentrations were monitored for three sampling rounds only and concentrations were never higher than 5 mg/L.

Phenols

Total phenols were detected at all surface water monitoring stations and ranged from 0.001 to 1.70 mg/L. However, only 2 of 14 samples from Stations SW1 and SW2 had detectable concentrations (i.e. >0.001 mg/L). These samples were collected on two different dates with the highest concentration (0.006 mg/L) encountered at SW1 on August 13, 1988.

Phenolic speciation was conducted on a water sample from SW1 in August 1988. All phenol species concentrations were below detection limits.

VOCs

Samples for VOCs were collected from sites SW1, SW2 and SW5 on August 13, 1988 only. Of the several VOCs analysed for, most were below detection limits. Small amounts of tetrachloroethylene (1.4 to 1.7 µg/L) were found at SW1 and SW2 but were the only results above the method detection limit on these samples. Low concentrations of tetrachloroethylene (1.0 µg/L), toluene (4.8 µg/L), xylene (1.1 µg/L) and other aromatics (6.3 µg/L) were found in a sample collected at SW5.

BTX

Benzene, toluene and xylene (BTX) were analysed in October 1988. Analysis of samples indicated concentrations below detection limits at stations SW1, SW2 and SW3. Detectable concentrations of BTX were encountered at SW4 with benzene accounting for 22 µg/L, toluene 13 µg/L and xylenes 30 µg/L of the total. Water samples from SW5 also had BTX, however, the concentrations were an order of magnitude lower than those at SW4 (total BTX 6.5 µg/L). Benzene (3.5 µg/L) and xylenes (3.0 µg/L) together accounted for the total BTX concentration.

Polyaromatic Hydrocarbons (PAHs)

PAH analysis was conducted on 13 surface water samples over the course of the study. In general, most of PAHs species in the water samples were found to be below detection limits particularly for samples from the West Davignon Diversion. However, water samples collected at SW4 (Spring Creek) and SW5 contained significant amounts of PAHs (43.8 to 7,710 $\mu\text{g/L}$ total PAH).

Total PAH concentrations in water samples from stations on the West Davignon Diversion (SW1 and SW2) showed similar trends during the two rounds of sampling at these stations. Low concentrations of naphthalene (0.02 to 0.1 $\mu\text{g/L}$) and phenanthrene (0.05 $\mu\text{g/L}$) were found at SW1 over the course of the study. Similarly, SW2 had low concentrations of naphthalene (0.01 to 0.03 $\mu\text{g/L}$) in 2 of 4 samples and phenanthrene (0.03 $\mu\text{g/L}$) in 1 of the 4 samples collected for PAH analysis. PAHs at these stations consisted of the lighter PAH species (naphthalene and phenanthrene). Two rounds of PAH sampling at SW3 indicated low concentrations (total PAH 0.5 $\mu\text{g/L}$) detected during October 1988 and all PAHs were below detection limits during April 1989.

Samples collected at SW4 and SW5 for PAH analyses indicated high PAH concentrations in both October and April. Total PAH concentrations in samples collected in October were greater than 710 $\mu\text{g/L}$ at SW4 and 274.7 $\mu\text{g/L}$ at SW5. The spring samples (April) showed the same relative distribution of PAHs but were generally lower in concentration (total PAH = 209.2 $\mu\text{g/L}$ at SW4 and 46.1/43.8 (laboratory duplicate analyses of one sample) $\mu\text{g/L}$ at SW5). Flow rates in the surface water channels were much higher during the spring sampling event and may account for the lower PAH concentrations by dilution.

Small amounts of PAHs were measured in samples collected at SW8 and SW9 in June 1989. Total PAH concentrations were 1.6 $\mu\text{g/L}$ and 1.9 $\mu\text{g/L}$ at SW8 and SW9 respectively. The PAHs present were generally the lower molecular weight PAHs; however, no naphthalene was present in either sample.

The PAH data from stations SW3 through SW9 indicate that there is significant dilution occurring in Bennett Creek downstream of the outfalls of SW4 and SW5. This is consistent with the findings for Cl and SO₄.

5.8.4 Metals

The first set of water samples (August 1988) were analysed for 22 metals to determine which metals analyses should be conducted with more and less frequency. Following a review of the metal analysis, it was decided that the alkali metals (particularly Ca, Mg, K, Na) would become standard analyses with complete metals analyses being conducted once or twice at each of the primary stations (SW1 through SW5) during the study.

Metal analysis results for all sites can be found in Appendix 11 with summary statistics of the data sets (by station) found in Appendix 12.

Stations SW1 and SW2

Cobalt, copper, lead, chromium, nickel, beryllium, vanadium and molybdenum were not detected at any time during the survey in the West Davignon Diversion (SW1 and SW2).

Cadmium was detected from samples in the August survey at both SW1 (0.0008 mg/L), SW2 (0.0006 mg/L) but in subsequent sampling rounds it was not detected in any of the samples collected from West Davignon Diversion. In addition, mercury, selenium and arsenic were not detected in the sample from SW1 collected during the August survey.

Metals which were found to be above detection were generally low in concentration with the exception of a few of the common metals such as calcium, iron and aluminum. All samples collected from SW1 and SW2 on the West Davignon Diversion had iron and aluminum concentrations which exceeded the PWQO.

Station SW3

Water samples collected at SW3 had many metals concentrations consistently below detection limits. These metals include lead, chromium, nickel, beryllium, molybdenum, cobalt, copper and vanadium. Metals with concentrations above detection limits in samples collected from SW3 were zinc, iron, calcium, aluminum, magnesium, potassium, strontium and sodium. Cadmium was found in water samples from at low concentrations in August (0.0002 mg/L) and September (0.0008 mg/L). Neither of these samples was above the PWQO of 0.0002 mg/L.

Zinc concentrations (0.025 to 0.04 mg/L) were found to be above the Aquatic Life Guideline in three of four samples collected in the fall of 1988 at this site. Iron (0.48 to 0.98 mg/L) and aluminum (0.42 and 0.52 mg/L) concentrations were consistently above the PWQO concentrations in samples collected at SW3.

Station SW4

Water samples taken at SW4 had many metals at concentrations above analytical detection limits. However, the concentrations of few metals exceeded the PWQO. Only lead and beryllium were not found above the detection limits. Metals which exceeded the ALG included cadmium, copper and iron (only one sample each) and aluminum (all samples tested). Calcium (480-600 mg/L), potassium (33-44 mg/L) and sodium (58-105 mg/L) concentration ranges were found to be consistently greater than levels at both SW3 and SW2.

Station SW5

The concentrations of several metals were consistently above PWQO at SW5. These include copper, iron, chromium, and aluminum. Three of four samples had nickel concentrations above the PWQO. Only lead and beryllium were consistently below detection limits.

Calcium concentrations were found to be extremely high in water samples taken at SW5 and ranged from 850 to 1,700 mg/L. Potassium concentrations (84 to 125 mg/L) and sodium concentrations (47 to 65 mg/L) were also very high compared with samples collected at SW3 and SW2.

Station SW6

Water samples taken at SW6 (upstream of SW4), had metals trends similar to station SW4. Cadmium, iron, and aluminum concentrations exceeded the PWQOs.

Station SW7

The single water sample collected from SW7 had zinc (0.05 mg/L), cadmium (0.0004 mg/L), and iron (0.60 mg/L) concentrations above the PWQO values. Both zinc and cadmium were found to be slightly higher in concentration in samples at this background site compared to the downstream site of SW3 collected the same day. In contrast, iron and manganese were higher in concentration at SW3 compared to SW7.

Summary

In summary, metals analyses from water samples collected at all surface water monitoring stations indicate that the highest concentrations and highest number of PWQO exceedences occurred station SW5. All sites had samples with PWQO exceedences, and the most consistent metals found to be problematic were iron and aluminum. Iron and aluminum were problematic at stations upstream of the Algoma slag site in addition to on-site stations. These metals are likely to be naturally occurring.

5.9 Creek Bed Sediments and Tarry Material

During the initial site reconnaissance in June 1988, tarry material was observed along the creek bed of Bennett Creek near the former Domtar facility. The presence of this material was the focus of two hydrogeologic investigations of the Domtar and surrounding area (GLL, 1988; CRA, 1988).

During the May sampling round, the tarry material on the creek bed of Bennett Creek (adjacent to SW4) was sampled along with the creek bed sediment for PAH and chlorophenol or oil and grease analysis. Results of the analyses are provided in Appendix 11.

The tarry material was comprised of very high concentrations of naphthalene (40,000 µg/g), anthracene (16,000 µg/g), benzo(a)anthracene (14,000 µg/g), benzo(a)pyrene (21,000 µg/g) and high concentrations (1,300 to 8,200 µg/g) of other PAHs. All PAHs tested were detected. The tarry material had a total PAH concentration of 152,800 µg/g.

Chlorophenol analysis indicated that the tarry material was comprised of 2,700 µg/g of 4-Nitrophenol. Other chlorinated phenols were much lower in concentration (38 µg/g 2,4-dinitrophenol; 60 µg/g 4,6-dinitro-o-cresol; 49 µg/g 4-chloro-3-methylphenol; 6 µg/g phenol; 3.2 µg/g m-cresol; 2.6 µg/g p-cresol).

The sediment sample collected from the bed of Bennett Creek was analysed for PAHs only. The total PAH concentration was 1,935 µg/g. PAH concentrations ranged from 7.4 µg/g (indeno 1,2,3-d,d pyrene) to 305 µg/g (flouranthrene). Higher concentrations were associated with the light to intermediate molecular weight PAHs (acenaphthene through to pyrene). Overall, the sediment PAH concentrations were 1 to 2 orders of magnitude lower than the tarry material. Sediment analysis indicated a high total oil and grease content of 19,000 µg/g.

5.10 Mass Flux Estimates

5.10.1 Dissolved Constituents

Daily average mass flux estimates were calculated for a number of dissolved constituents for stations SW1 through SW5 and are found in Table 5.8. Mass flux (or loading) estimates at each station were determined for constituents which were detected in at least three water samples. Loading estimates were calculated from the product of the mean concentration (statistics conducted on log transformed data to account for the non-normal distribution of surface water quality parameters) and the mean annual daily flow. In certain cases, for comparative purposes, loads were produced from the mean concentration of only 2 water samples. These are identified as weighted average estimates in Table 5.8. Loading estimates have been calculated for each station while SW4 and SW5 are discharges totally originating on-site. SW2 subtracted from SW1 represents loadings from surface water on the West Davignon Diversion side while SW3, SW4 and SW5 represent loading to the vessel slip on the east side of the slag site. Estimated total loadings to St. Marys River from on-site sources only for West Davignon Diversion and Bennett Creek are found in Table 5.9.

The surface water load estimates are as reliable as the data from which they are produced. The surface water flow monitoring program was designed to account for flow either monthly or semi-continuously over the study periods. Major assumptions have been made in the development of the individual station flow data. Whenever possible mean annual flow averages have been used to produce loads. Compounding the load estimate errors are errors or variability associated with water quality data. Mean concentrations were used to determine loads to minimize the variability of individual sample data. In addition, water quality statistics were performed on log transformed data to account for skewed (low concentration) distribution of most water quality/water quantity parameters.

Chloride loadings were on the same order of magnitude for all sites even though flows were much higher at SW1, SW2, and SW3. Site-related chloride loads ranged from 105 kg/d for Spring Creek to 800 kg/d for Bennett Creek.

Sulphate loadings for West Davignon Diversion (1127 kg/d) were much higher than the sulphate loadings for the other creeks (19.2 to 211 kg/d). Similarly nitrate and TKN loadings were over an order of magnitude greater for the West Davignon Diversion than for the other creeks (see Spring Creek and Baseline Road ditch on Table 5.8 and Bennett Creek on Table 5.9). Total phosphorus and phenols loadings were similar (2.30 to 5 g/d TP, 10.8 to 39.2 g/d for phenols) for those creeks with estimated loadings. Compared with the total load of nitrate and phosphorus in Bennett Creek, the site-related loads are very small (approximately 1%).

All creeks contributed site-related PAHs to the St. Marys River. The PAH loads were high for Bennett Creek (95 g/d), Baseline Road ditch (54 g/d) and Spring Creek (40.8 g/d), and lower for West Davignon Diversion (0.3 g/d).

Generally, the metals loadings from site sources were greatest for the West Davignon Diversion (see Table 5.9). These high loading rates arise because of the high flow rates in the channel, and not because metals concentrations were significantly higher for this creek. Metals loads contributed by the other creeks were all approximately the same and significantly less than those for West Davignon Diversion.

5.10.2 Estimated Flux of Tarry Materials

The flux of tarry materials in the creek beds of Bennett Creek and Spring Creek was not quantified during this study; however, approximations of this flux can be made based on chemical analyses and the volume of material removed from the creek bed. Algoma personnel estimated approximately 1,000 to 2,000 imperial gallons of tarry material had been removed by 46 vacuum truck loads (5,000 gallon capacity). Assuming a density of 1.05 kg/L for the

tarry material and based on the chemical data presented in Section 5.9, between 730 and 1530 kg of PAH were removed. This material would likely have made its way to the St. Marys River if it had not been removed. The estimate of PAH removed from the creek bed is that for only a short time period. Total loading of PAHs to the St. Marys River via migration in the tarry phase could be much greater than the dissolved mass loading and likely constitutes a much more serious environmental concern than the migration of dissolved PAHs.

6.0 COMPARISON OF MASS FLUXES

Volumetric and mass (dissolved load) fluxes from the Algoma slag site to the St. Marys River have been calculated for groundwater and stream flow based on actual analytical and field data collected over a one-year period. This chapter provides a comparison of groundwater and stream flow discharge rates and loads. The total mass flux from the Algoma slag site is compared with loadings to the St. Marys River from other sources (municipal and industrial point sources and a direct non-point source) which have been documented in the Upper Great Lakes Connecting Channels Study (UGLCCS - see King, 1988).

6.1 Comparison of Groundwater and Stream Volumetric Discharges

Table 6.1 provides a comparison of the estimated groundwater flux to streams (see Section 3.5.8) with measured surface water flow rates in those streams (see Section 5.7). This comparison is important because it provides a verification of the discharge estimates which were calculated independently for groundwater and surface water. Groundwater and surface water estimates of discharge through Baseline Road ditch and Spring Creek agree very well (estimates differ by less than 35%). This agreement occurs because these creeks receive water only from on-site groundwater discharge. The groundwater flux estimates and surface water flow measurements for Bennett Creek and West Davignon Diversion also compare well. Groundwater discharge to Bennett Creek and the West Davignon Diversion were a very small part of the total flow in the creeks (<1%) which were not measurable using the techniques employed for flow measurement during the surface water study. The flow contribution by the Algoma slag site was less than the precision of the surface water flow measurements for these creeks (i.e. no measurable difference between upstream and downstream flow rates).

6.2 Comparison of Groundwater and Surface Water Mass Flux Estimates

Mass flux estimates for groundwater and corresponding surface water dissolved loads for selected parameters are listed in Table 6.2. Total surface water loads for Spring Creek and Baseline Road ditch (see Table 5.8), and site contribution loads (i.e. downstream load minus upstream load) for West Davignon Diversion and Bennett Creek (see Table 5.9) are shown in the table. Groundwater mass flux data are from Table 5.2. Only those constituents for which there are both groundwater and surface water data are shown.

Generally, the surface water and groundwater mass fluxes compare well for Baseline Road ditch. Parameters which do not compare well include chloride, sulphate, total phosphorus, PAHs, and a few metals. For these parameters, surface water loads were generally one to two orders of magnitude greater than the groundwater mass flux estimates. As discussed in Section 3.9.2, the groundwater mass fluxes were thought to be underestimated because chemical data on which these estimates were based was not likely to be representative of the groundwater discharging to the ditch. This is likely to be the reason for the discrepancy in the estimates.

The surface water fluxes at Bennett Creek are consistently one to two orders of magnitude greater than the groundwater mass fluxes. This discrepancy likely occurs because the surface water estimates for contribution by the Algoma slag site do not adequately account for upstream source loads and because the contribution from the east bank of the creek which is not site related could not be differentiated from the site-related contribution from the west bank.

Groundwater and surface water mass flux estimates for Spring Creek compare quite well for a number of parameter such as fluoride, TKN, total phosphorus, phenols, aluminum, iron potassium and sodium. Most metals (for which there are mass flux estimates) were generally an order of magnitude higher for the surface water estimate, while groundwater PAH flux

estimates were two orders of magnitude higher than surface water estimates. Groundwater mass flux estimates for Spring Creek are based on water chemistry at only one well (B1) which may not be representative of the groundwater quality discharging to Spring Creek. This could be the reason for this discrepancy.

The comparison of mass flux estimates for the West Davignon Diversion shows large discrepancies between the groundwater mass flux and surface water loads. Surface water loads were consistently two to three orders of magnitude higher than groundwater mass fluxes. Errors or discrepancies in mass loadings are likely due to the inaccuracy of the surface water estimates. Groundwater discharge to the West Davignon Diversion is negligible compared to total flow in the diversion channel. Consequently, site-related stream load calculation was subject to error.

6.3 Summary of Off-Site Mass Flux

The total flux of dissolved mass from the Algoma slag site was estimated using a combination groundwater and surface water data. Total site-related fluxes are summarized in Table 6.3. Fluxes to Spring Creek and Baseline Road ditch based on surface water measurements are shown in Table 6.3 because these measurements are based on monthly monitoring and are more likely to reflect the true stream loads than the groundwater mass flux data. Fluxes to West Davignon Diversion and Bennett Creek are based on groundwater mass flux from the site to these creeks because net surface water estimates were inaccurate for these creeks (see Section 6.2).

The flux of dissolved constituents is generally highest to Baseline Road ditch or the St. Marys River directly via the shoreline, except for BTX and PAHs which are highest to Spring Creek. The flux of dissolved constituents is lowest to West Davignon Diversion.

6.4 Significance of Off-Site Mass Flux

The UGLCCS contains compiled data on the loading of chemical constituents to the St. Marys River from various point and non-point sources. In general, point sources include effluents from municipal and industrial wastewater treatment facilities directly to the river and indirectly through its tributaries. Non-point sources include atmospheric deposition, intermittent stormwater discharges, combined sewer overflows, rural land runoff, navigation, groundwater discharge and release from bottom sediments. Table 6.4 lists the point and non-point sources for which St. Marys River loading data were given in the UGLCCS. Table 6.4 also summarizes the total flux of constituents from the Algoma slag site (see Table 6.3). Only constituents for which loadings are reported in the UGLCCS are presented in Table 6.4, although more information is presented in Table 6.3.

The Algoma slag site contributes negligible amounts of the total load of total phosphorous, cyanide, phenols, copper, iron, and zinc to the St. Marys River. The site contributes 3% of the total chloride load to the St. Marys River. Of more significance are the BTX and PAH loading -- the site contributes 15% and 32% of the total loads of BTX and PAH respectively. The loads shown for the Algoma slag site are dissolved phase loads only.

The BTX and PAH loads shown in Table 6.4 do not account for off-site migration of pure phase liquids or as suspended sediment loads. As discussed in Chapters 3.0 and 5.0, migration of even small volumes of DNAPL tarry material or contaminated creek sediment would constitute a much greater mass flux of PAHs and BTX to the St. Marys River. The fluxes of this type have not been quantified by this study.

1. The inventory of wastes and by-products on-site and leachability tests conducted on selected materials from the Algoma slag site indicate that the constituents of environmental concern likely to be associated with these materials include PAHs, volatile aromatics, phenols, cyanide, ammonia, metals and acid.
2. The Algoma slag site is underlain by an unconfined aquifer comprised of the slag (and other fill) material, shallow sand, and organic silt units. A deeper confined aquifer comprised of the basal sand and gravel and bedrock units, is separated from the unconfined aquifer by a low-permeability laminated clay and silt unit beneath the eastern part of the site, and a moderately permeable shallow silty sand and silty sand till beneath the western part of the site.
3. Regional groundwater flow is from the north toward the St. Marys River south of the Algoma slag site. Locally, groundwater flow is radially outward from an area of elevated water levels beneath the central western slag disposal area toward the West Davignon Diversion, Baseline Road ditch and the St. Marys River. Components of vertical flow are upward from the bedrock to the natural unconsolidated sediments everywhere on site except within the central area where downward gradients occur. Discharge of groundwater occurs to the West Davignon Diversion, Bennett Creek, Spring Creek and the Baseline Road ditch which all flow to the St. Marys River, as well as directly to the St. Marys River via the shoreline. Groundwater discharges to each of the St. Marys River (directly) and the Baseline Road ditch at an approximate rate of $10^5 \text{ m}^3/\text{yr}$. Discharge to Bennett Creek and Spring Creek is less (approximately $10^4 \text{ m}^3/\text{yr}$). Groundwater discharge to the West Davignon Diversion ($10^2 \text{ m}^3/\text{yr}$) is small relative to the other on-site creeks and the St. Marys River.

4. The main areas identified as sources for chemical constituents to the groundwater were the central slag area (comprised of acid dump, sludge dump (including the tar dump area), oil pond and filter cake dump), the vicinity of the former Domtar facility, and the dredged sediments at the aggregate operation. Sulphate, chloride and specific conductance plumes emanate from the central slag area as a result of the disposal of lime fines and pickling liquor. Phenols and PAHs are associated with all three source areas, while volatile organics (BTX) are associated with the central slag and Domtar areas. Metals are associated with the main slag area and dredged river sediments; however, the mobility of many metals is restricted by the high pH of the groundwater in most areas of the site. Constituents in the groundwater below source areas are also found in groundwater from areas adjacent to discharge areas.
5. Hydraulic gradients within the confined aquifer are directed toward the south. No evidence of hydraulic gradient reversal was found indicating that groundwater from beneath the Algoma slag site does not migrate toward the city water supply wells. Naturally occurring isotopes and chemical data indicate that contamination of the confined aquifer by shallow groundwater beneath the site has not occurred. Furthermore, the hydraulic gradients are upward from the confined aquifer to the unconfined aquifer which suggests contamination of the confined aquifer by shallow groundwater is not likely to occur.
6. Seepage of groundwater through the St. Marys River bed has been confirmed at two offshore sites adjacent to the Algoma slag site. These sites were found to have sediment electrical conductances significantly elevated over other areas of the St. Marys River bed adjacent to the site. The chemistry of water obtained from river bed mini-piezometers was comparable to shallow groundwater obtained from adjacent on-site monitoring wells.

7. Surface infiltration measurements indicate that, even during extreme rainfall events, most precipitation (less evaporation) infiltrates through the slag surface and is incorporated into the groundwater regime. Surface runoff will not result in the direct discharge of water to receiving water bodies. The only significant pathway for site-related constituents to migrate to surface water is through the subsurface.
8. All of the flow through Baseline Road ditch and Spring Creek can be attributed to groundwater discharge from the Algoma slag site. Less than 1% of the total flow in Bennett Creek and the West Davignon Diversion is attributed to groundwater discharge from the site.
9. Water samples from Spring Creek, Bennett Creek and Baseline Road ditch generally had higher concentrations of dissolved constituents (chloride, sulphate, nitrate, TKN, phenols) than did water samples from West Davignon Diversion. VOC concentrations were generally quite low (up to 6.3 µg/L) for all surface water stations. Water samples from Spring Creek and Baseline Road ditch contained BTX and PAHs. Most metals concentrations, with the exception of the alkali metals, were quite low; however, several samples had metals concentrations in excess of Provincial Water Quality Objectives.
10. The site-related (i.e. source of constituents is the Algoma slag site) dissolved chloride loads were approximately the same for all creeks; however, sulphate, nitrate and TKN loads were greatest for the West Davignon Diversion. All creeks contributed PAHs to the St. Marys River. PAH loads were high for Baseline Road ditch, Spring Creek and Bennett Creek (40.8 to 95 g/d) and much lower for West Davignon Diversion (0.3 g/d).
11. The Algoma slag site contributes negligible amounts of the total load of total phosphorus, cyanide, phenols, copper, iron and zinc loads to the St. Marys River from

various documented point and non-point sources. The site contributes about 3% of the total chloride load. Most significantly, the site contributes 15% of the BTX and 32% of the PAH total load to the St. Marys River.

8.0 - RECOMMENDATIONS

1. Data collected during this investigation indicate that groundwater within the confined aquifer beneath the Algoma slag site does not move to the north toward the city water supply wells and that dissolved constituents originating from the shallow subsurface will not migrate downward to the confined aquifer. Monitoring of water levels on-site and at the city water supply wells should be conducted to confirm that groundwater within the confined aquifer is flowing south toward the St. Marys River and does not flow from the Algoma slag site to the water supply wells and that vertical gradients are consistently upward so that downward migration does not occur.
2. Order of magnitude estimates for the flux of dissolved constituents from the Algoma slag site to the St. Marys River have been determined based on information collected during this investigation. The mass fluxes have been compared to loadings from point and non-point sources to the St. Marys River which have been documented to date to determine the environmental significance of the fluxes. Only those parameters for which there are data for comparison with have been evaluated in terms of environmental significance -- other constituents (for example, fluoride, cadmium) were not evaluated in this way. Additional information regarding loadings from point and non-point sources to the St. Marys River is required to assess the environmental significance of other constituents from the Algoma slag site. Additionally, the effects of discharges to the St. Marys River from the Algoma slag site require study to fully determine the environmental impact of these discharges. Such a study could include a benthic survey of the river bottom adjacent to and downstream from the site.
3. The flux of dissolved PAHs and BTX from the Algoma slag site to the St. Marys River is estimated to be approximately 15 and 32% of the total loads of PAH and BTX (respectively) to the St. Marys River from all documented sources. Although these percentages are significant, the loading resulting from separate phase migration

in the subsurface and creek beds was not quantified during this investigation. The actual loading of PAH and BTX to the St. Marys River from the Algoma slag site is likely to be considerably greater if the flux of separate phase tarry materials is included with the dissolved loads. As this is likely to be a much more significant contribution of constituents to the St. Marys River, the flux of separate phase materials requires quantification to truly assess this impact. A study to quantify this type of migration should address both migration of the tarry material as a separate phase, and migration of the tarry material bound to suspended sediments discharging to the St. Marys River along with the creek water.

9.0 REFERENCES

- Baumgartner, N., D.E. Elrick and K.L. Bradshaw. 1987. In-situ hydraulic conductivity measurements of slowly permeable materials using a modified Guelph Permeameter and the Guelph Infiltrometer. Proceedings: National Water Well Association, Las Vegas, Nevada.
- Canadian Steel Environmental Association (CSEA). 1983. Solid waste leachate analysis. Letter from A.E. Kruzins, Dofasco to A.D. Stewart, Algoma, 23.11.83.
- Conestoga Rovers and Associates (CRA). 1988. Phase II Hydrogeologic Investigation. Report prepared for Algoma Steel Corp. Ltd., Sault Ste. Marie. December 1988.
- Chow, V.T. 1959. Open-Channel Hydraulics. McGraw-Hill Book Co., New York.
- Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice-Hall, Inc., NJ.
- Gartner Lee Ltd. (GLL). 1988. Hydrogeologic Study Domtar Coal Tar Plant, Sault Ste. Marie. Interim Report on Phase II Studies. Report prepared for Domtar Inc., April 1988.
- Geocon Inc. (Geocon). 1983. Hydrogeologic Investigation, Slag Dump Area. The Algoma Steel Corp. Ltd., Sault Ste. Marie. Report prepared for Algoma Steel Corp. Ltd.
- Hvorslev, M.J. 1951. Time Log Soil Permeability in Groundwater Observations. U.S. Army Corps Engrs. Waterways Exp. Sta. Bull. 36, Vicksburg, Miss.

-
- King, L. (Environment Canada). 1988. Upper Great Lakes Connecting Channels Study.
Volume I Geographic Area Report. St. Marys River Canadian Point Sources and
Volume II.
- Kirkpatrick, G.A. and P.E. Shelley. 1975. Sewer Flow Measurement - a State-of-the-Art
Assessment. EPA Environmental Protection Technology Series,
EPA-600/2-75-027.
- Kulin, G. and P.R. Compton. 1975. A Guide to Methods and Standards for Flow
Measurement of Water Flow. National Technical Information Service,
Springfield, VA.
- Lee, D.R. and J.A. Cherry. 1978. A field exercise on groundwater flow using seepage meters
and mini-piezometers. J. Geol. Education, Vol. 27: 6-10.
- Lee, D.R. and S.J. Welch. 1988. Research and development of methods for locating and
estimating contaminant loading via groundwater entering the St. Marys River.
Penultimate Report submitted to Ontario Ministry of the Environment, Sarnia.
- Marsalek, J. 1976. Instrumentation for Field Studies of Urban Runoff Research Report No.
42, Canada-Ontario Agreement on Great lakes Water Quality, Environment
Canada, Ottawa.
- Munch, J.H. and R.W.D. Killey. 1985. Equipment and methodology for sampling and testing
cohesionless sediments. Ground Water Monitoring Review, Vol. 5, No. 1: 38-42.
- Ontario Ministry of the Environment. 1982. Manual of Policy, Procedures and Guidelines
for Private Sewage Disposal Systems.

Reynolds, W.D. and D.E. Elrick. 1986. A method for simultaneous in-situ measurements in the vadose zone of field saturated hydraulic conductivity, sorptivity and the conductivity-pressure head relationship. Groundwater Monitoring Review, 84-95.

Sirman Associates Ltd. 1985. Evaluation of Slag and Its Potential Impact on the Aquatic Environment. Report prepared for Environmental Protection Service, Environment Canada.

Streeter, V.L. and Wylie, E.B. 1981. Fluid Mechanics (1st Metric Edition). McGraw-Hill Book Co., New York.

Welch, S.J. and D.R. Lee. 1988. A method for installing and monitoring piezometers in beds of surface waters. Ground Water Vol. 27, No. 1: 87-90.

Criteria for Evaluation of Water and Sediments

MOE: Water Management Goals, Policies and Objectives. 1984 (Tables 1 and 4).

MOE: Persaud and Wilkinds. 1975.

WHO: Guidelines for Drinking Water Quality, Vol. 2. 1984.

IJC: Great Lakes Water Quality Agreement. 1978. Reports of the Aquatic Ecosystem Objectives Committee. 1980, 1981, 1983a, 1985.

EPA: Water Quality Criteria Documents. Federal Register 45: 99318. 1980. Quality Criteria for Water. 1976.

TABLE 2.1: MATERIALS, BY-PRODUCTS AND WASTES AT THE ALGOMA WASTE DISPOSAL SITE AND ASSOCIATED AREA

Material, By-Product or Waste	Description	Disposal or Storage Practice	Disposal Rate	Constituents of Environmental Significance
Steel-Making Wastes				
BF and BOF Slag	Gangue material after removal of iron, primarily calcium aluminum silicate	disposed over entire site	71,120 tonnes/month	fluoride, metals
Pickling Liquor	Hydrochloric acid used in cleaning steel rolls	dumped into neutralization pit at acid dump	38,000 L/d	metals, acid
Lime Fines	Gypsum and spent lime used in BOF	disposed in central dump area	50 tonnes/month	sulphate, metals
Filter Cake	Filter material from thickener and wet scrubber, includes material from BF, BOF and sinter plant precipitation dust	disposed west of lime fines	2,000 tonnes/month	metals, fluoride, PAHs
Waste Oils	Oil-contaminated process waters	pumped into oil separation pond, oil pumped off water	280,000 L oil and water/month	PAH, volatile aromatics, phenols
Pollution Abatement Equipment Sludges	Scrubber sludges and baghouse dusts	disposed at sludge dump	5-25 m ³ /month	metals
Dunnage	Waste paper, wood blocking, waste bricks	disposed at west site area	NI	TOC
PCB-containing Oils	Machinery and rags with PCB-containing oils	containers placed in steel vaults on concrete pads, south site area	NI	PCB, phenols, PAHs, volatile aromatics
Coking By-Products and Wastes				
Coal and Coke	Materials used in steel-making	stored in piles west of boat slip	-	PAHs
Tar	By-product of pyrolysis of coal to coke and coal gasification	currently found in subsurface of Domtar and surrounding area. tar-like material disposed in sludge dump area	NI	PAHs, phenols, volatile aromatics
Coke Oven Gas Line Condensate	Condensation in gas lines from coking operation	prior to 1980, disposed in slag dump	NI	cyanide, metals, PAHs
Decanter Sludge	Heavy fraction remaining after production of coke	disposed in sludge dump, north of filter cake	60 tonnes/month	PAHs, cyanide, metals ammonia, phenols
Box Oxide Wastes	Gas purification wastes, wood shavings used to remove H ₂ S from gas	found in subsurface at former gas plant	no record of disposal at dump	PAHs, cyanide, metals
Other Wastes				
Sediments	Dredged river sediments	disposed in former lagoon in A.B. MacLean	NI	zinc, oil and grease

NI - no information

TABLE 2.2: SCHEDULE OF LEACH TEST MATERIALS AND TEST TYPES

Sample Description	Sample No.	Leach Test Type	Analytical Level ²
Recent Materials			
Oil pond residue	RS-1	309	2
Acid dump residue	RS-2	HCl	2+CN
Lime fines	RS-6	HCl	1
Lime fines	182 ³	309	CSEA ³
BOF slag	RS-7	HCl	1
BOSP slag	181 ³	309	CSEA ³
BF slag	179 ³	309	CSEA ³
Filter cake	RS-9	HCl and NaOH	2+CN
BOSP filter cake	178 ³	309	CSEA ³
BF filter cake	180 ³	309	CSEA ³
Decanter sludge	RS-10	HCl and NaOH	2+CN
Contaminated coke	RS-11	309	2
Contaminated Subsurface Materials¹			
Sand (antiseptic odour)	D3-6.4	NaOH	2+CN
Sandy sludge (naphthalene odour)	C4-4.6	NaOH	2+CN
Sand (pungent odour)	A1-7.6	309	2
Sand (rotten odour)	A2-5.8	309	2
Natural Subsurface Materials¹			
Sand (no odour)	B4-18.6	NaOH	1
Clay (no odour)	A7-12.5	NaOH	1

¹ Sample number is comprised of borehole number and depth (m) from which sample is obtained.

² Analyses conducted are listed in Table 2.3.

³ Leachability studies conducted by the Canadian Steel Environmental Association. Analyses include anions, cations, TOC, phenols and cyanide.

TABLE 2.3: ANALYTICAL PARAMETERS FOR LEACHATE TESTS

Parameter	Level 1	Level 2	Level 3
Anions ¹	Yes	Yes	Yes
Oil and Grease	Yes	No	No
Phenols	Yes	Yes	Yes
Metals ²	Yes	Yes	Yes
Sulphide ³	No	Yes	Yes
TKN	No	Yes	Yes
PAHs	No	Yes	Yes
DOC	Yes ⁴	Yes	Yes

¹ Anions analysed: Cl, Br, F, SO₄, NO₃-N; F analyses were not performed on Regulation 309 leachates because of analytical interference by acetic acid. Cl analyses were not performed on HCl leachates.

² Metals analysed:
 Level 1: Zn, Cd, Mn, Co, Cu, Fe, Pb, Cr, Ni
 Level 2 and 3: Level 1 metals plus Be, Mo, Ca, Va, Al, Mg, Ba, K, Sr, Na

³ Only alkaline leachates were analysed for sulphide.

⁴ DOC analyses not conducted on Level 1 leachates.

TABLE 2.4:

SELECTED METALS CONCENTRATIONS IN LEACHATES

Sample	Test Type	Concentration (mg/L)							
		Zn	Mn	Pb	Cu	Fe	Cr	Ni	Al
Recent Materials									
Oil Pond Residue RS-1	309	0.42	30.5	-	0.015	456	-	0.035	10
Contaminated Coke RS-11	309	0.25	0.44	-	-	-	-	-	-
Acid Dump Residue RS-2	HCl	0.09	35	-	0.020	330	0.16	0.41	1.10
Lime Fines RS-6	HCl	-	-	-	0.015	-	0.15	0.06	NA
Lime Fines 182	309	0.07	-	-	0.030	-	-	0.06	-
BOF Slag RS-7	HCl	-	6.1	-	-	-	-	-	NA
BOF Slag 181	309	-	-	-	0.018	-	-	-	0.44
BF Slag 179	309	-	-	-	-	-	-	-	0.44
Filter Cake RS-9	HCl	0.09	5.3	0.10	0.028	-	0.07	0.08	0.71
Filter Cake RS-9	Alk	-	-	-	0.020	-	-	-	0.48
BOF Filter Cake 178	309	0.08	-	-	0.015	-	-	-	-
BF Filter Cake 180	309	-	-	-	0.008	-	-	-	1.08
Decanter Sludge RS-10	HCl	0.48	1.42	7.8	0.020	60	0.08	0.79	0.14
Decanter Sludge RS-10	Alk	-	-	-	-	0.42	-	-	0.24
Contaminated Subsurface Materials									
Borehole D3	Alk	0.04	-	-	0.055	-	-	-	4.4
Borehole C4	Alk	-	-	-	0.035	-	-	0.03	0.64
Borehole A1	309	-	14.6	-	0.010	8.1	-	-	2.2
Borehole A2	309	-	36	-	0.010	0.78	-	0.02	0.86
Natural Subsurface Materials									
Borehole B4	Alk	-	-	-	-	-	-	-	NA
Borehole A7	Alk	-	-	-	-	-	-	-	NA
Drinking Water Guideline ¹		5	0.05	0.050	1	0.3	0.05	0.001 ²	0.2 ³
Aquatic Life Guideline ⁵		0.030		0.025	0.005	0.3	0.10	0.025	0.1 ⁴

Concentration does not exceed either aquatic life or drinking water guideline.

NA

Not analysed

1

MOE Maximum Acceptable Concentration unless otherwise stated.

2

EPA Federal Register (1976).

3

WHO (1984).

4

IJC (1985).

5

MOE (1984), Provincial Water Quality Objective unless otherwise stated.

TABLE 2.5: TOTAL PAHs AND PHENOLS CONCENTRATIONS IN LEACHATES

Sample	Leach Test Type	Concentration	
		Total PAH (µg/L)	Phenols (mg/L)
Recent Materials			
Oil Pond Residue RS-1	309	>500	0.032
Contaminated Coke RS-11	309	3	0.001
Acid Dump Residue RS-2	HCl	1.5	<0.001
Lime Fines RS-6	HCl	NA	0.002
Lime Fines 182	309	NA	0.008
BOF Slag RS-7	HCl	NA	<0.001
BOSP Slag 181	309	NA	0.010
BF Slag 179	309	NA	0.006
Filter Cake RS-9	HCl	0.4	<0.001
Filter Cake RS-9	Alkaline	88.9	0.001
BOSP Filter Cake 178	309	NA	0.011
BF Filter Cake 180	309	NA	0.008
Decanter Sludge RS-10	HCl	>700	1.66
Decanter Sludge RS-10	Alkaline	>600	2.5
Contaminated Subsurface Materials			
Borehole D3	Alkaline	1.8	0.011
Borehole C4	Alkaline	>500	0.062
Borehole A1	309	375.7	0.060
Borehole A2	309	0.7	0.005
Natural Subsurface Materials			
Borehole A7	Alkaline	NA	0.008
Borehole B4	Alkaline	NA	0.005

NA - not analysed

TABLE 3.1:

SCHEDULE OF ANALYTICAL LEVELS FOR GROUNDWATER SAMPLES

Monitoring Well	ANALYTICAL LEVEL			
	Summer 1988	Fall 1988	Winter 1989	Spring 1989
A1-1	1	2	1	1
A1-2	3	2	1	1
A2-1	2	1	1	1
A2-2	2	2	1	1
A3	1	1	no access	no access
A4-1	1	1	2 + PAH, BTX, TKN, P	2 + PAH
A4-2	1	1	frozen	2 + TKN, P, PAH, BTX
A5	2	2	2 + PAH	2 + TKN, P
A6	1	1	2 + TKN, P, PAH, BTX	2 + PAH
A7-1	1	3	frozen	3
A7-2	1	1	2 + TKN, P, PAH, BTX	2 + PAH
B1	3	2	1	1
B2-1	2	2 + TKN, P	pump lost	2 + PAH, BTX
B2-2	2	2 + TKN, P	2 + PAH	2
B2-3	Not installed	2 + TKN, P	2 + PAH	2
B3	1	2	2 + PAH, TKN, P, BTX	2 + PAH
B4-1	1	2 + TKN, P	2 + PAH	2
B4-2	1	2 + TKN, P	2 + PAH	2
B5	1	2	2 + PAH, TKN, P, BTX	2 + PAH
C1	1	1	1	1
C2-1	1	1	1	1
C2-2	dry	dry	dry	dry
C3	1	1	1	1
C4	3	3	3	3
D1-1	1	2 + TKN, P, PCB	2 + PAH, PCB	2 + PCB
D1-2	1	2 + TKN, P, PCB	2 + PAH, PCB	2 + PCB
D2	1	1	2 + PAH, TKN, P, BTX	2 + PAH
D3-1	1	2 + TKN, P	2 + PAH	2
D3-2	2	3	3	3
D4	1	1	2 + PAH, TKN, P, BTX	2 + PAH
D5-1	1	2 + TKN, P	2 + PAH	2
D5-2	1	2 + TKN, P	2 + PAH	2
D6	1	1	2 + PAH, TKN, P, BTX	2 + PAH
Trip Blanks	1 @ level 3	1 @ level 2	1 @ level 2 + BTX TKN, P, PAH	1 @ BTX, PAH
Replicates	2 @ level 1	1 @ level 2 + PCB, P, TKN	1 @ level 1 1 @ level 2 + PAH	3 @ PAH, 1 @ BTX

See Table 3.2 for list of analyses for each level

TABLE 3.2: ANALYTICAL SCHEME FOR GROUNDWATER SAMPLES

SAMPLING EVENT	Summer 1988			Fall 1988			Winter 1989			Spring 1989		
ANALYTICAL LEVEL	1	2	3	1	2	3	1	2	3	1	2	3
PARAMETER												
DIC	-	X	X	-	-	X	-	-	X	-	-	X
Alkalinity	-	X	X	X	X	X	X	X	X	X	X	X
Anions	X	X	X	X	X	X	X	X	X	X	X	X
Sulphide	-	X	X	-	-	-	-	-	X	-	-	X
Total Cyanide	-	-	X	-	X	X	-	X	X	-	X	X
Ca, Mg, Na, K	-	-	-	X	X	-	X	-	-	X	-	-
9 Metals ¹	X	-	-	-	-	-	-	-	-	-	-	-
19 Metals ²	-	X	X	-	-	X	-	X	X	-	X	X
As, Se, Hg	-	-	X	-	-	X	-	-	X	-	-	X
Ammonia-N	-	-	X	-	-	X	-	-	X	-	-	X
TKN	-	X	X	-	O	X	-	O	X	-	O	X
Total Phosphorus	-	-	X	-	O	X	-	O	X	-	O	X
DOC	X	X	X	X	-	X	X	-	X	X	X	X
Oil & Grease	X	-	-	-	-	-	-	-	-	-	-	-
Total Phenols	X	X	X	X	X	X	X	X	X	X	X	X
Phenol Species	-	-	X	-	-	-	-	-	-	-	-	-
PCBs	-	-	X	-	O	X	-	O	X	-	O	X
VOCs	-	X	X	-	-	-	-	-	-	-	-	-
BTX	-	-	-	-	X	X	-	O	X	-	O	X
PAHs	-	X	X	-	X	X	-	O	X	-	O	X

X - parameter included

O - parameter optional, included for some Level 2 analyses (see Table 3.1)

- parameter not included

¹ - Nine metals analysed are Zn, Cd, Mn, Co, Cu, Fe, Pb, Cr and Ni² - Nineteen metals analysed are above nine plus Be, Mo, Ca, Va, Al, Mg, Ba, K, Sr and Na

TABLE 3.3: SUMMARY OF CREEK BED MINI-PIEZOMETERS CONSTRUCTION

Piezometer Number	Tubing Elevation (m amsl)	Location	Installation Method	Length of Piezometer (m)	Stick Up (m)	Stick Up to Tubing Top (m)	Total Depth (mbgs)	Comments
Location A								
CBA1-1	NM	east bank	hammer	1.31	0.65	0.72	0.66	encountered rock
CBA1-2	NM	east bank	back hoe	1.95	0.80	0.87	1.15	
CBA2-1	185.76	east bank, west of CBA1-1	hammer	1.65	0.70	0.80	0.95	encountered rock
CBA2-2	NM	east bank west of CBA1-1	back hoe	2.12	0.70	NM	1.42	
CBA3-1	NM	west bank	hammer	1.65	0.95	1.03	0.70	encountered rock
Location B								
CBB1-1	185.28	east bank	hammer	1.80	0.43	0.50	1.37	
CBB1-2	NM	east bank	hammer	3.30	0.80	0.87	2.50	excavation - 12-15" boulders (6-12" diam.) 6-10" gravel (2-3"), stony red sand till
CBB2-1a	NM	west bank	hammer	1.65	0.40	0.65	1.25	may be broken at base
CBB2-1b	NM	west bank	hammer	1.65	0.20	0.55	1.45	
CBB2-1c	NM	west bank	hammer	1.65	0.05	0.60	1.60	
CBB2-2	NM	west bank	back hoe	2.20	0.70	0.77	1.50	

... continued

TABLE 3.3: SUMMARY OF CREEK BED MINI-PIEZOMETERS CONSTRUCTION

Piezometer Number	Tubing Elevation (m amsl)	Location	Installation Method	Length of Piezometer (m)	Stick Up (m)	Stick Up to Tubing Top (m)	Total Depth (mbgs)	Comments
Location C								
CBC1-1	NM	north side of Baseline Road	hammer	1.80	1.12	1.14	0.68	soft fine-grained sediment
CBC1-2	185.19	north side of Baseline Road	hammer	3.77	1.00	1.02	2.77	
CBC1-3	NM	north side of Baseline Road	hammer	5.20	1.02	1.09	4.18	
CBC2-1	NM	centre of Baseline Road	hammer	1.80	0.40	0.70	1.40	
CBC2-2	NM	centre of Baseline Road	hammer	3.50	0.40	0.70	3.10	
CBC3-1	NM	south side of Baseline Road	hammer	2.15	1.45	1.48	0.70	
CBC3-2	NM	south side of Baseline Road	hammer	3.75	1.45	1.48	2.30	

m amsl - metres above mean sea level
 mbgs - metres below ground surface
 NM - not measured

TABLE 3.4: WATER LEVEL MEASUREMENTS, CREEK BED MINI-PIEZOMETERS

Date	Fall 1988		Spring 1989		
Mini-Piezometer Number	Δh	Δh Relative To	Depth to Groundwater (mbtt)	Depth to Stream Water (mbtt)	Δh Relative to Surface Water
CBA1-1	0.06	SW	0.92	NM	NM
	>1.0	CBA1-2			
CBA1-2	>1.0	SW	1.04	NM	NM
CBA2-1	NM	NM	1.23	1.50	NM
CBA2-2	NM	NM	1.46	1.31	NM
CBA3-1	NM	NM	1.36	NM	NM
CBB1-1	0.48	SW	NM	NM	0.69
	0.30	CBB1-2			
CBB1-2	0.25	SW	2.58	1.51	NM
CBB2-1a	NM	NM	NM	NM	0.52
CBB2-2	NM	NM	NM	NM	0.50
CBC1-1	NM	NM	NM	0.48	-0.44
CBC1-2	0.49	SW	NM	NM	0.06
CBC1-3	>1.0	SW	2.00	0.52	NM
	0.65	CBC1-2			
CBC2-1	NM	NM	0.65	0.52	NM
CBC2-2	NM	NM	2.00	0.54	NM
CBC3-1	NM	NM	1.06	0.78	NM
CBC3-2	NM	NM	2.40	0.78	NM

mbtt metres below top of tubing

SW surface water

NM not measured

Δh hydraulic head elevation difference

"+ve" groundwater level higher than creek water level

"-ve" groundwater level lower than creek water level

TABLE 3.5: SUMMARY OF CREEK MINI-PIEZOMETER DEVELOPMENT AND SAMPLING, SPRING 1989

Mini-Piezometer	Volume Pumped (mL)	Parameters Analysed						Comments
		General ¹	Total Cyanide	Phenols	BTX	PAH	19 Metals	
CBA1-1	1,250	X	X	X	X	X	X	oily odour, clear, quick to yield
CBA1-2	100	X		X				clear, oily odour, slow to yield
CBA2-1	10				not sampled			slow to yield
CBA2-2	50				not sampled			slow to yield
CBA3-1	10				not sampled			slow to yield
CBB1-1	1,000	X	X	X	X	X	X	clear, quick to yield
CBB1-2	200				not sampled			silty, slow to yield
CBB2-1	100	X	-	X	-	-	-	silty, slow to yield
CBB2-2a	100			composited with B2-1				silty, slow to yield
CBC1-1	100				not sampled			slow to yield
CBC1-2	750	X	X	X	X	X	X	quick to yield
CBC1-3	300	X	X	X	X	X	X	dark, silty, slow to yield
CBC2-1	100	X		insufficient water for complete analysis				slow to yield
CBC2-2	300	X		insufficient water for complete analysis				medium to yield
CBC3-1	100	X		insufficient water for complete analysis				slow to yield
CBC3-2	150	X		insufficient water for complete analysis				slow to yield

¹ General parameters are anions, dissolved organic carbon, alkalinity, TKN and total phosphorus.

TABLE 3.6: SUMMARY OF HYDRAULIC CONDUCTIVITIES

Hydrostratigraphic and Geologic Unit	Hydraulic Conductivity (m/s)		Number of Tests
	Range	Average ¹	
<u>Unconfined Aquifer</u>			
Slag Fill	9.4x10 ⁻⁶ to 2.2x10 ⁻⁴	5.2x10 ⁻⁵	4
Fill (excluding slag)	1.4x10 ⁻⁶ to 7.3x10 ⁻⁵	8.7x10 ⁻⁶	4
Shallow Sand (east site)	1.2x10 ⁻⁶ to 6.4x10 ⁻⁴	8.7x10 ⁻⁵	18
Organic Silt (semi- confining unit)	1.6x10 ⁻⁶ to 3.2x10 ⁻⁵	4.8x10 ⁻⁶	4
<u>Aquitard</u>			
Shallow Silty Sand (west site)	4.6x10 ⁻⁸ to 2.9x10 ⁻⁵	1.9x10 ⁻⁶	4
Silty Sand Till	9.8x10 ⁻⁸ to 1.0x10 ⁻⁵	6.8x10 ⁻⁷	4
Laminated Clay & Silt	2.0x10 ⁻⁹ to 4.2x10 ⁻⁷	3.0x10 ⁻⁸	9
<u>Confined Aquifer</u>			
Basal Sand and Gravel	1.6x10 ⁻⁴	1.6x10 ⁻⁴	1
Bedrock	6.2x10 ⁻⁹ to 1.6x10 ⁻⁵	1.7x10 ⁻⁶	18

¹ - arithmetic mean of log transformed hydraulic conductivity values.

Table 3.7: SUMMARY OF HORIZONTAL HYDRAULIC GRADIENTS

Well Pair	Separation (m)*	Hydraulic Gradient by Date											Summary of Hydraulic Gradients			
		5/6-Aug-88	7-Aug-88	8-Aug-88	9/10-Aug-88	4-Oct-88	16-21-Nov-88	3-Dec-88	11-Feb-89	6-10-Mar-89	29-31-May-89	1-Jun-89	Maximum	Minimum	Average	Standard Deviation
WEST SITE																
C3/C1	550	0.0072	0.0074	0.0073	0.0074	0.0074	0.0075	0.0074	NM	0.0074	0.0075	0.0075	0.0075	0.0072	0.0074	0.0001
C3/D4	750	0.0093	0.0094	0.0094	0.0094	0.0093	0.0094	0.0091	0.0095	0.0097	0.0094	0.0094	0.0097	0.0091	0.0094	0.0002
C3/D5-2	670	0.0099	0.0099	0.0099	0.0099	0.0099	0.0099	0.0098	0.0099	0.0100	0.0099	0.0099	0.0100	0.0098	0.0099	0.0000
C3/A2-2	700	NM	0.0044	0.0044	0.0044	0.0042	0.0043	NM	NM	0.0044	0.0044	0.0043	0.0044	0.0042	0.0044	0.0001
C3/D6	500	0.0084	0.0088	0.0085	0.0084	0.0071	0.0066	0.0077	0.0088	0.0092	0.0088	0.0096	0.0096	0.0066	0.0083	0.0009
C3/A1-2	250	NM	NM	NM	NM	0.0139	0.0128	0.0129	0.0139	0.0141	0.0135	0.0135	0.0141	0.0128	0.0135	0.0005
C3/C4	370	0.0135	0.0136	0.0135	0.0136	0.0131	NM	0.0099	0.0133	NM	0.0132	0.0132	0.0136	0.0099	0.0130	0.0011
EAST SITE																
A6/A5	350	NM	0.0042	0.0042	0.0041	0.0052	0.0056	0.0053	NM	0.0042	0.0044	0.0043	0.0041	0.0056	0.0046	0.0005
A6/B1	850	NM	NM	NM	NM	0.0038	0.0038	0.0035	NM	0.0037	NM	0.0034	0.0038	0.0034	0.0036	0.0002

NM: Static water level not measured.

* - Separation distance adjusted perpendicular to watertable contours on Figure 3.5.

TABLE 3.8: VERTICAL GRADIENTS AT THE ALGOMA SLAG SITE

Monitoring Well Nest Location	<u>VERTICAL HYDRAULIC GRADIENT</u>						
	Oct. 88	Nov. 88	Dec. 88	Feb. 89	Mar. 89	May 89	June 89
A1	-5.0×10^{-3}	-2.8×10^{-3}	-3.6×10^{-3}	-1.6×10^{-2}	-1.6×10^{-2}	-2.1×10^{-2}	-2.4×10^{-2}
A2	1.3×10^{-1}	1.3×10^{-1}	NM	NM	9.0×10^{-2}	1.2×10^{-1}	NM
A4	$6.8 \times 10^{-4*}$	7.7×10^{-2}	2.2×10^{-2}	NM	NM	-5.7×10^{-3}	-7.7×10^{-3}
A7	4.7×10^{-2}	2.5×10^{-2}	8.4×10^{-3}	NM	NM	-1.0×10^{-2}	3.3×10^{-3}
B2 (-1, -2)	5.3×10^{-2}	4.1×10^{-2}	3.1×10^{-2}	4.3×10^{-2}	4.5×10^{-2}	2.7×10^{-2}	2.5×10^{-2}
B2 (-2, -3)	NM	NM	NM	NM	1.9×10^{-2}	1.5×10^{-2}	1.4×10^{-2}
B4	4.1×10^{-2}	3.7×10^{-2}	3.6×10^{-2}	NM	3.8×10^{-2}	3.2×10^{-2}	2.2×10^{-2}
D1	1.0×10^{-2}	1.0×10^{-2}	0.0	1.7×10^{-2}	7.3×10^{-3}	1.8×10^{-2}	1.2×10^{-2}
D3	1.8×10^{-2}	-3.7×10^{-3}	3.0×10^{-3}	NM	1.2×10^{-2}	3.0×10^{-3}	NM
D5	2.6×10^{-2}	5.5×10^{-2}	2.5×10^{-2}	2.2×10^{-2}	5.4×10^{-3}	2.4×10^{-2}	1.2×10^{-2}
GEOCON 1	NM	NM	NM	NM	NM	NM	-3.8×10^{-2}
GEOCON 4	NM	NM	NM	NM	NM	NM	3.9×10^{-2}
GEOCON 9	NM	NM	NM	NM	NM	NM	-6.6×10^{-3}

NM = not measured

"+" gradient is directed upward

"-" gradient is directed downward

* shallow water level suspect

TABLE 3.9: VERTICAL GRADIENTS AT THE CREEK BED MINI-PIEZOMETERS

Data Pair	Vertical Separation (m)	Fall 1988		Spring 1989	
		Δh (m)	Gradient	Δh (m)	Gradient
<u>Location A - West Davignon Creek</u>					
CBA1-1 and CBA1-2	0.49	>0.94	>1.9	0.03	0.06
CBA2-1 and CBA2-2	0.47	NM	NM	-0.42	-0.89
<u>Location B - West Davignon Creek</u>					
CBB1-1 and CBB1-2	1.16	0.30	0.26	-1.39	-1.20
CBB2-1a and CBB2-2	0.25	NM	NM	-0.02	-0.08
<u>Location C - Baseline Road Ditch</u>					
Creek Bed and CBC1-1	0.68	NM	NM	-0.44	-0.65
CBC1-1 and CBC1-2	2.09	NM	NM	0.50	0.24
CBC1-2 and CBC1-3	1.41	0.65	0.40	-1.54	-1.09
Creek Bed and CBC2-1	1.40	NM	NM	-0.13	-0.09
CBC2-1 and CBC2-2	1.70	NM	NM	-1.33	-0.78
Creek Bed and CBC3-1	0.70	NM	NM	-0.28	-0.40
CBC3-1 and CBC3-2	1.60	NM	NM	-1.33	-0.83

Δh - hydraulic head elevation difference

NM - not measured

"+ve" gradients are directed upward

"-ve" gradients are directed downward

TABLE 3.10: RESULTS OF TRITIUM ANALYSES - GROUNDWATER
SAMPLES, ALGOMA

Monitoring Well	Tritium Concentration (TU)	
	Winter 1989	Spring 1989
A4-1	1.2±0.9	NA
A7-1	NA	68.3±4.6
B2-1	NA	48.6±3.1/50.8±3.4*
B2-3	25.6±1.9	24.2±1.8
B4-1	4.9±0.7	NA
D3-1	0.8±0.6	NA
D5-1	43.3±3.0/44.4±3.1*	NA

* duplicate analyses

NA not analysed

TABLE 3.11: SUMMARY OF GROUNDWATER FLUX CALCULATIONS

Receiving Water Body	Element	Flux (m ³ /yr)		
		Average	Minimum	Maximum
St. Marys River	A	9.9x10 ⁴	1.3x10 ⁴	5.3x10 ⁵
	C	9.1x10 ⁴	4.9x10 ³	6.3x10 ⁵
	E	<u>3.2x10⁴</u>	<u>9.7x10²</u>	<u>2.9x10⁵</u>
Total		2.2x10 ⁵	1.9x10 ⁴	1.4x10 ⁶
Baseline Road Ditch	C	1.3x10 ⁵	3.9x10 ³	9.5x10 ⁵
	D	<u>3.8x10⁴</u>	<u>9.7x10²</u>	<u>3.7x10⁵</u>
Total		1.7x10 ⁵	4.9x10 ³	1.3x10 ⁶
Bennett Creek	D	3.8x10 ⁴	8.2x10 ²	3.6x10 ⁵
Spring Creek	F	3.6x10 ⁴	3.5x10 ²	3.6x10 ⁵
West Davignon Diversion	B	2.6x10 ²	1.4x10 ¹	8.1x10 ³
Total Groundwater Discharge		4.6x10 ⁵	2.5x10 ⁴	3.5x10 ⁶

TABLE 3.12: COMPARISON OF GROUNDWATER FLUX AND RECHARGE RATES

Element	Total Avg. Flux (m ³ /yr)	Total Recharge (m ³ /yr)
A	9.9x10 ⁴	4.9x10 ⁵
B	2.6x10 ²	1.9x10 ⁵
C	2.2x10 ⁵	4.4x10 ⁵
D	7.6x10 ⁴	4.0x10 ⁵
E and F	<u>6.8x10⁴</u>	<u>1.5x10⁵</u>
Site Total	4.6x10 ⁵	1.6x10 ⁶

Table 3.13: SUMMARY OF GROUNDWATER VELOCITY ESTIMATES

	Hydraulic Conductivity (m/s)			Hydraulic Gradient			Porosity			Velocity (m/yr)		
	average	minlimum	maximum	average	minlimum	maximum	typical	maximum	minlimum	average	minlimum	maximum
HORIZONTAL VELOCITIES												
WEST SITE												
Unconfined Aquifer												
Slag Fill	5.2E-05	9.4E-06	2.2E-04	0.012	0.0066	0.014	0.35	0.40	0.30	5.6E+01	4.9E+00	3.2E+02
Shallow Sand	8.7E-05	1.2E-06	6.4E-04	0.012	0.0066	0.014	0.35	0.40	0.30	9.4E+01	6.2E-01	9.4E+02
Confined Aquifer												
Basal Sand and Gravel	1.6E-04	1.6E-04	1.6E-04	0.012	0.0066	0.014	0.35	0.40	0.30	1.7E+02	8.3E+01	2.4E+02
Bedrock	1.7E-06	6.2E-09	1.6E-05	0.012	0.0066	0.014	0.20	0.40	0.15	3.2E+00	3.2E-03	4.7E+01
EAST SITE												
Unconfined Aquifer												
Slag Fill	5.2E-05	9.4E-06	2.2E-04	0.0041	0.0034	0.0056	0.35	0.40	0.30	1.9E+01	2.5E+00	1.3E+02
Shallow Sand	8.7E-05	1.2E-06	6.4E-04	0.0041	0.0034	0.0056	0.35	0.40	0.30	3.2E+01	3.2E-01	3.8E+02
Confined Aquifer												
Basal Sand and Gravel	1.6E-04	1.6E-04	1.6E-04	0.0041	0.0034	0.0056	0.35	0.40	0.30	5.9E+01	4.3E+01	9.4E+01
Bedrock	1.7E-06	6.2E-09	1.6E-05	0.0041	0.0034	0.0056	0.20	0.40	0.15	1.1E+00	1.7E-03	1.9E+01
VERTICAL VELOCITIES*												
UPWARD												
Aquitard												
Laminated Clay and Silt	3.0E-08	2.0E-09	4.2E-07	0.033	0.003	0.13	0.35	0.40	0.30	8.9E-03	4.7E-05	5.7E-01
Shallow Silty Sand	1.9E-06	4.6E-08	2.9E-05	0.033	0.003	0.13	0.35	0.40	0.30	5.6E-01	1.1E-03	4.0E+01
Silty Sand Till	6.8E-07	9.8E-08	1.0E-05	0.033	0.003	0.13	0.35	0.40	0.30	2.0E-01	2.3E-03	1.4E+01
DOWNWARD												
Aquitard												
Laminated Clay and Silt	3.0E-08	2.0E-09	4.2E-07	0.019	0.0066	0.038	0.35	0.40	0.30	5.1E-03	1.0E-04	1.7E-01
Shallow Silty Sand	1.9E-06	4.6E-08	2.9E-05	0.019	0.0066	0.038	0.35	0.40	0.30	3.2E-01	2.4E-03	1.2E+01
Silty Sand Till	6.8E-07	9.8E-08	1.0E-05	0.019	0.0066	0.038	0.35	0.40	0.30	1.2E-01	5.1E-03	4.0E+00

* Vertical hydraulic conductivity assumed to be 1/10 the horizontal hydraulic conductivity presented for calculation of vertical velocities.

TABLE 3.14:

CLASSIFICATION OF WELLS ACCORDING TO LOCATION

	North Site	Shallow Source Area	Deep Source Area	Shallow Site Perimeter	Deep Site Perimeter
A1-1			X		
A1-2		X			
A2-1			X		
A2-2		X			
A3		X			
A4-1			X		
A4-2		X			
A5	X				
A6	X				
A7-1	X				
A7-2	X				
B1		X			
B2-1					X
B2-2				X	
B2-3					X
B3				X	
B4-1					X
B4-2				X	
B5				X	
C1		X			
C2-1		X			
C2-2		dry			
C3		X			
C4		X			
D1-1					X
D1-2				X	
D2				X	
D3-1					X
D3-2				X	
D4				X	
D5-1					X
D5-2				X	
D6		X ¹		X ¹	

¹ Well D6 was included in both shallow source area and shallow site perimeter classifications because it was located adjacent to the slag escarpment but also along West Davignon Diversion.

Table 3.15: SUMMARY OF NORTH SITE AREA GROUNDWATER CHEMISTRY

PARAMETER	Number	Number	Detection	Average	Standard	Minimum	Maximum	Location of	Water Criteria	
	Samples	Detects	Frequency	Conc.*	Deviation*	Conc.†	Conc.‡	Maximum	PWQO	MAC
pH	15	15	100	9.6	1.4	7.9	12.3	A5	6.5-8.5	NV
SPECIFIC CONDUCTANCE (µS/cm)	15	15	100	505	423	180	1730	A5	NV	NV
TEMPERATURE (C)	14	14	100	9.1	1.7	6.0	12.0	A6	NV	NV
DISSOLVED OXYGEN	10	10	100	3.9	1.6	0.7	6.5	A7-1	NV	NV
DIC	3	3	100	11.07	1.72	9.00	13.20	A7-1	NV	NV
ALKALINITY	12	12	100	170.50	129.56	41.00	550.00	A5	NV	NV
SULPHIDE	3	1	33	0.03	0.05	0.10	0.10	A5	NV	NV
TOTAL CYANIDE	9	2	22	0.003	0.005	0.008	0.015	A5	0.005	0.2
BROMIDE	15	5	33	0.03	0.04	0.05	0.14	A5	NV	NV
CHLORIDE	15	15	100	10.41	5.85	1.49	18.30	A5	NV	NV
FLUORIDE	15	15	100	0.30	0.24	0.04	0.90	A5	NV	1.5
SULPHATE	15	15	100	9.93	4.80	2.90	22.00	A5	NV	500
NITRATE-N	15	10	67	0.10	0.18	0.01	0.68	A7-1	NV	10
AMMONIA-N	2	2	100	0.29	0.26	0.04	0.55	A7-1	0.02	NV
TOTAL KJELDAHL NITROGEN	5	4	80	7.00	8.31	0.16	18.20	A5	NV	NV
TOTAL PHOSPHOROUS	4	3	75	0.04	0.04	0.04	0.10	A5	0.03	NV
DOC	11	9	82	5.65	11.15	0.50	40.00	A5	NV	NV
PHENOLS	15	9	60	0.037	0.059	0.001	0.143	A5	0.001	NV
PCB (µg/L)	2	0	0	ND	ND	ND	ND		0.001	NV
OIL AND GREASE	3	1	33	1.00	1.41	3.00	3.00	A6	NV	NV
ZINC	12	3	25	0.00	0.00	0.01	0.01	A7-2	0.03	NV
CADMIUM	12	4	33	0.0002	0.0003	0.0004	0.0008	A7-1	0.0002	0.005
MANGANESE	12	11	92	0.07	0.06	0.01	0.17	A6	NV	NV
COBALT	12	0	0	ND	ND	ND	ND		NV	NV
COPPER	12	6	50	0.005	0.007	0.005	0.025	A7-2	0.005	NV
IRON	12	12	100	0.25	0.31	0.02	0.98	A5	0.3	NV
LEAD	12	0	0	ND	ND	ND	ND		0.025	0.05
CHROMIUM	12	1	8	0.00	0.00	0.01	0.01	A5	0.1	0.05
NICKEL	12	1	8	0.00	0.00	0.01	0.01	A5	0.025	0.00134*
BERYLLIUM	9	0	0	ND	ND	ND	ND		NV	NV
MOLYBDENUM	9	3	33	0.01	0.01	0.01	0.04	A5	NV	NV
CALCIUM	12	12	100	54.59	38.35	14.50	136.00	A5	NV	NV
VANADIUM	9	5	56	0.01	0.01	0.01	0.03	A5	NV	NV
ALUMINUM	9	9	100	0.32	0.30	0.02	0.86	A7-2	0.15	0.2†
MAGNESIUM	12	12	100	4.08	3.07	0.15	9.50	A6	NV	NV
BARIUM	9	9	100	0.03	0.02	0.01	0.05	A5	NV	1
POTASSIUM	12	12	100	4.30	3.86	1.15	10.80	A5	NV	NV
STRONTIUM	9	9	100	0.19	0.13	0.06	0.50	A5	NV	NV
SODIUM	12	12	100	29.13	25.66	4.00	90.00	A5	NV	NV
ARSENIC (µg/L)	2	1	50	1	1	1	1	A7-1	100	50
SELENIUM (µg/L)	2	0	0	ND	ND	ND	ND		100	10
MERCURY (µg/L)	2	1	50	0.08	0.08	0.15	0.15	A7-1	0.2	1
BTX (µg/L)										
BENZENE	5	0	0	ND	ND	ND	ND		NV	5
TOLUENE	5	1	20	5.6	11.2	28.0	28.0	A7-2	NV	NV
XYLENE	5	1	20	19.6	39.2	98.0	98.0	A7-2	NV	NV
TOTAL BTX	5	1	20	25.2	50.4	126.0	126.0	A7-2	NV	NV
PAHs (µg/L)										
NAPHTHALENE	9	4	44	2.74	3.49	2.30	9.10	A5	NV	NV
ACEPHTHYLENE	9	1	11	0.01	0.02	0.05	0.05	A5	NV	NV
ACEPHTHENE	9	3	33	0.06	0.09	0.15	0.20	A5	NV	NV
FLUORENE	9	3	33	0.03	0.05	0.10	0.10	A5	NV	NV
PHENTHRENE	9	5	56	1.23	1.42	0.10	3.46	A5	NV	NV
ANTHRACENE	9	3	33	0.04	0.05	0.10	0.13	A5	NV	NV
FLUORANTHENE	9	5	56	0.48	0.61	0.10	1.90	A6	NV	NV
PYRENE	9	4	44	0.27	0.34	0.40	1.00	A6	NV	NV
BENZO(a)ANTHRACENE	9	0	0	ND	ND	ND	ND		NV	NV
CHRYSENE	9	2	22	0.08	0.19	0.10	0.60	A6	NV	NV
BENZO(b)FLUORANTHENE	9	1	11	0.08	0.22	0.70	0.70	A6	NV	NV
BENZO(k)FLUORANTHENE	9	0	0	ND	ND	ND	ND		NV	NV
BENZO(a)PYRENE	9	0	0	ND	ND	ND	ND		NV	0.01
PERYLENE	9	0	0	ND	ND	ND	ND		NV	NV
INDENO(1,2,3-C,D)PYRENE	9	0	0	ND	ND	ND	ND		NV	NV
DIBENZO(a,h)ANTHRACENE	9	0	0	ND	ND	ND	ND		NV	NV
BENZO(g,h,i)PERYLENE	9	0	0	ND	ND	ND	ND		NV	NV
TOTAL PAHs	9	5	56	5.02	5.75	0.20	14.27	A5	NV	NV

NV: No value.
ND: Not detected.

PWQO: Provincial Water Quality Objective (unless otherwise noted).
MAC: Maximum Acceptable Concentration (unless otherwise noted).

* EPA Federal Register (1976).
† WHO (1984).
‡ IJC (1978).

* - for calculation of average and standard deviation, concentrations which are non-detectable are assumed to be zero
‡ - minimum or maximum detectable concentration

Table 3.16: SUMMARY OF SOURCE AREA SHALLOW GROUNDWATER CHEMISTRY

PARAMETER	Number Samples	Number Detects	Detection Frequency	Average Conc.*	Standard Deviation*	Minimum Conc.‡	Maximum Conc.‡	Location of Maximum	Water Criteria PWQO	MAC
pH	37	37	100	8.0	1.5	6.3	12.2	C3	6.5-8.5	NV
SPECIFIC CONDUCTANCE (µS/cm)	37	37	100	2297	1688	180	7020	A1-2	NV	NV
TEMPERATURE (C)	37	37	100	11.1	3.3	4.0	23.0	B1	NV	NV
DISSOLVED OXYGEN	25	23	92	3.7	2.7	0.3	9.6	C3	NV	NV
DIC	7	7	100	47.86	15.04	33.00	80.00	C4	NV	NV
ALKALINITY	33	33	100	201.88	164.13	76.00	760.00	D6	NV	NV
SULPHIDE	6	2	33	5.34	11.92	0.04	32.00	C4	NV	NV
TOTAL CYANIDE	13	11	85	0.064	0.066	0.002	0.210	A2-2	0.005	0.2
BROMIDE	38	3	8	0.02	0.10	0.05	0.60	A2-2	NV	NV
CHLORIDE	38	38	100	104.63	138.30	1.14	470.00	C4	NV	NV
FLUORIDE	38	37	97	2.31	3.06	0.05	11.00	A1-2	NV	1.5
SULPHATE	38	38	100	842.06	1030.98	2.30	4700.00	A1-2	NV	500
NITRATE-N	38	14	37	0.55	1.16	0.04	4.50	A2-2	NV	10
AMMONIA-N	6	6	100	2.39	4.50	0.02	12.40	A1-2	0.02	NV
TOTAL KJELDAHL NITROGEN	9	9	100	3.01	5.24	0.39	17.70	A1-2	NV	NV
TOTAL PHOSPHOROUS	8	7	88	0.05	0.06	0.01	0.17	A1-2	0.03	NV
DOC	34	34	100	62.33	135.39	1.00	670.00	A1-2	NV	NV
PHENOLS	38	27	71	0.301	0.801	0.001	3.800	A1-2	0.001	NV
PCB (µg/L)	5	0	0	ND	ND	ND	ND		0.001	NV
OIL AND GREASE	6	4	67	4.17	3.44	3.00	9.00	C3	NV	NV
ZINC	16	14	88	0.03	0.03	0.01	0.10	A1-2	0.03	NV
CADMIUM	16	10	63	0.0005	0.0006	0.0002	0.0020	C2-1	0.000	0.005
MANGANESE	16	15	94	21.02	77.20	0.10	320.00	A1-2	NV	NV
COBALT	16	7	44	0.01	0.02	0.01	0.08	A1-2	NV	NV
COPPER	16	7	44	0.003	0.005	0.005	0.015	A1-2	0.005	NV
IRON	16	16	100	45.73	148.68	0.02	620.00	A1-2	0.3	NV
LEAD	16	1	6	0.03	0.10	0.40	0.40	A1-2	0.025	0.05
CHROMIUM	16	8	50	0.01	0.02	0.01	0.06	A1-2	0.1	0.05
NICKEL	16	7	44	0.01	0.01	0.01	0.04	A1-2	0.025	0.00134*
BERYLLIUM	10	0	0	ND	ND	ND	ND		NV	NV
MOLYBDENUM	10	7	70	0.03	0.03	0.01	0.06	C4&A1-2	NV	NV
CALCIUM	32	32	100	215.35	156.81	15.20	550.00	C1	NV	NV
VANADIUM	10	5	50	0.02	0.02	0.01	0.07	A1-2	NV	NV
ALUMINUM	10	10	100	0.27	0.31	0.04	1.16	A1-2	0.1V	0.2†
MAGNESIUM	32	32	100	82.55	121.07	0.00	620.00	A1-2	NV	NV
BARIUM	10	10	100	0.06	0.03	0.03	0.14	A1-2	NV	1
POTASSIUM	32	32	100	88.72	152.12	1.65	690.00	C-1	NV	NV
STRONTIUM	10	10	100	0.62	0.53	0.08	2.10	A1-2	NV	NV
SODIUM	32	32	100	111.98	90.78	11.50	310.00	A1-2	NV	NV
ARSENIC (µg/L)	6	6	100	6	2	3	8	A1-2&C4	100	50
SELENIUM (µg/L)	6	0	0	ND	ND	ND	ND		100	10
MERCURY (µg/L)	6	3	50	0.10	0.13	0.05	0.35	C-4	0.2	1
BTX (µg/L)										
BENZENE	9	6	67	5124.3	13079.7	62.0	42000.0	A1-2	NV	5
TOLUENE	9	6	67	163.1	296.3	1.0	870.0	A1-2	NV	NV
XYLENE	9	6	67	234.4	461.3	3.0	1500.0	A1-2	NV	NV
TOTAL BTX	9	7	78	5521.9	13797.2	4.0	44370.0	A1-2	NV	NV
PAHs (µg/L)										
NAPHTHALENE	14	10	71	76.97	223.60	0.40	880.00	B1	NV	NV
ACEPHTHYLENE	14	10	71	52.46	165.64	0.28	182.00	B1	NV	NV
ACEPHTHENE	14	10	71	93.98	389.23	0.14	2100.00	B1	NV	NV
FLUORENE	14	10	71	146.38	490.41	0.15	1700.00	B1	NV	NV
PHENTHRENE	14	10	71	72.50	315.24	0.05	150.00	B1	NV	NV
ANTHRACENE	14	11	79	29.24	103.53	0.30	540.00	B1	NV	NV
FLUORANTHENE	14	9	64	27.64	102.15	0.06	110.00	B1	NV	NV
PYRENE	14	8	57	47.77	207.83	0.03	1120.00	B1	NV	NV
BENZO(a)ANTHRACENE	14	8	57	69.53	236.56	0.02	660.00	B1	NV	NV
CHRYSENE	14	6	43	46.73	146.00	0.03	450.00	B1	NV	NV
BENZO(b)FLUORANTHENE	14	4	29	38.09	112.01	0.40	410.00	B1	NV	NV
BENZO(k)FLUORANTHENE	14	4	29	27.26	82.65	0.50	158.00	B1	NV	NV
BENZO(a)PYRENE	14	4	29	25.79	80.43	0.53	400.00	B1	NV	0.01
PERYLENE	14	4	29	21.66	75.89	0.10	78.00	B1	NV	NV
INDENO(1,2,3-C,D)PYRENE	14	4	29	14.28	36.27	0.30	140.00	B1	NV	NV
DIBENZO(a,h)ANTHRACENE	14	3	21	11.03	32.40	0.15	36.00	B1	NV	NV
BENZO(g,h,i)PERYLENE	14	3	21	7.38	19.67	0.47	75.00	B1	NV	NV
TOTAL PAHs	14	11	79	392.84	1664.54	0.70	8886.80	B1	NV	NV

NV: No value.
ND: Not detected.

PWQO: Provincial Water Quality Objective (unless otherwise noted).
MAC: Maximum Acceptable Concentration (unless otherwise noted).

* EPA Federal Register (1976).
† WHO (1984).
‡ IJC (1978).

- for calculation of average and standard deviation, concentrations which are non-detectable are assumed to be zero.
‡ - minimum and maximum detectable concentration.

Table 3.17: SUMMARY OF SOURCE AREA DEEP GROUNDWATER CHEMISTRY

PARAMETER	Number Samples	Number Detects	Detection Frequency	Average Conc.*	Standard Deviation*	Minimum Conc.‡	Maximum Conc.‡	Location of Maximum	Water Criteria PWQO	MAC
pH	12	12	100	8.0	1.4	6.0	10.8	A4-1	6.5-8.5	NV
SPECIFIC CONDUCTANCE (µS/cm)	12	12	100	2492	3192	150	9590	A1-1	NV	NV
TEMPERATURE (C)	12	12	100	9.9	2.1	6.0	13.0	A2-1	NV	NV
DISSOLVED OXYGEN	9	7	78	3.5	2.2	2.4	6.8	A2-1	NV	NV
DIC	1	1	100	36.00	0.00	36.00	36.00	A2-1	NV	NV
ALKALINITY	10	10	100	87.50	33.42	37.00	135.00	A2-1	NV	NV
SULPHIDE	1	0	0	ND	ND	ND	ND		NV	NV
TOTAL CYANIDE	3	1	33	0.004	0.006	0.012	0.012	A1-1	0.005	0.2
BROMIDE	12	3	25	0.51	1.65	0.05	6.00	A1-1	NV	NV
CHLORIDE	12	12	100	509.15	731.68	2.00	1870.00	A1-1	NV	NV
FLUORIDE	12	10	83	0.69	1.03	0.16	3.50	A1-1	NV	1.5
SULPHATE	12	12	100	548.77	705.30	3.90	1600.00	A1-1	NV	500
NITRATE-N	12	8	67	0.38	0.59	0.01	2.00	A1-1	NV	10
AMMONIA-N	0	0	0	ND	ND	ND	ND		0.02	NV
TOTAL KJELDAHL NITROGEN	2	2	100	0.29	0.15	0.14	0.43	A2-1	NV	NV
TOTAL PHOSPHOROUS	1	1	100	0.05	0.00	0.05	0.05	A4-1	0.03	NV
DOC	10	10	100	55.95	82.25	1.00	200.00	A1-1	NV	NV
PHENOLS	12	9	75	0.803	1.460	0.001	4.800	A1-1	0.001	NV
PCB (µg/L)	0	0	0	ND	ND	ND	ND		0.001	NV
OIL AND GREASE	2	1	50	11.50	11.50	23.00	23.00	A1-1	NV	NV
ZINC	5	2	40	0.01	0.02	0.01	0.05	A1-1	0.03	NV
CADMIUM	5	3	60	0.0016	0.0027	0.0002	0.0070	A1-1	0.0002	0.005
MANGANESE	5	5	100	17.08	33.96	0.01	85.00	A1-1	NV	NV
COBALT	5	1	20	0.01	0.02	0.06	0.06	A1-1	NV	NV
COPPER	5	4	80	0.008	0.005	0.005	0.015	A4-1	0.005	NV
IRON	5	5	100	66.24	131.88	0.16	330.00	A1-1	0.3	NV
LEAD	5	1	20	0.02	0.04	0.10	0.10	A1-1	0.025	0.05
CHROMIUM	5	1	20	0.01	0.02	0.05	0.05	A1-1	0.1	0.05
NICKEL	5	2	40	0.01	0.01	0.01	0.03	A1-1	0.025	0.00134*
BERYLLIUM	3	0	0	ND	ND	ND	ND		NV	NV
MOLYBDENUM	3	2	67	0.01	0.01	0.01	0.02	A2-1	NV	NV
CALCIUM	10	10	100	235.45	312.45	10.50	730.00	A1-1	NV	NV
VANADIUM	3	1	33	0.01	0.00	0.01	0.01	A2-1	NV	NV
ALUMINUM	3	3	100	0.29	0.17	0.16	0.52	A4-1	0.15	0.2†
MAGNESIUM	10	10	100	76.67	110.00	1.00	270.00	A1-1	NV	NV
BARIUM	3	3	100	0.02	0.01	0.01	0.04	A2-1	NV	1
POTASSIUM	10	10	100	46.96	62.20	2.20	147.00	A1-1	NV	NV
STRONTIUM	3	3	100	0.31	0.18	0.17	0.56	A2-1	NV	NV
SODIUM	10	10	100	65.60	58.92	22.00	165.00	A1-1	NV	NV
ARSENIC (µg/L)	0	0	0	ND	ND	ND	ND		100	50
SELENIUM (µg/L)	0	0	0	ND	ND	ND	ND		100	10
MERCURY (µg/L)	0	0	0	ND	ND	ND	ND		0.2	1
BTX (µg/L)										
BENZENE	2	2	100	33506.0	33494.0	12.0	67000.0	A1-1	NV	5
TOLUENE	2	2	100	1302.0	1278.0	24.0	2580.0	A1-1	NV	NV
XYLENE	2	1	50	366.5	366.5	733.0	733.0	A1-1	NV	NV
TOTAL BTX	2	2	100	35174.5	35138.5	36.0	70313.0	A1-1	NV	NV
PAHs (µg/L)										
NAPHTHALENE	4	1	25	0.01	0.01	0.02	0.02	A2-1	NV	NV
ACEPHTHYLENE	4	1	25	0.58	1.00	2.30	2.30	A1-1	NV	NV
ACEPHTHENE	4	1	25	0.25	0.43	1.00	1.00	A1-1	NV	NV
FLUORENE	4	1	25	0.10	0.17	0.40	0.40	A1-1	NV	NV
PHENTHRENE	4	1	25	0.20	0.35	0.80	0.80	A1-1	NV	NV
ANTHRACENE	4	1	25	0.10	0.17	0.40	0.40	A1-1	NV	NV
FLUORANTHENE	4	1	25	0.03	0.04	0.10	0.10	A1-1	NV	NV
PYRENE	4	0	0	ND	ND	ND	ND		NV	NV
BENZO(a)ANTHRACENE	4	0	0	ND	ND	ND	ND		NV	NV
CHRYSENE	4	0	0	ND	ND	ND	ND		NV	NV
BENZO(b)FLUORANTHENE	4	0	0	ND	ND	ND	ND		NV	NV
BENZO(k)FLUORANTHENE	4	0	0	ND	ND	ND	ND		NV	NV
BENZO(a)PYRENE	4	0	0	ND	ND	ND	ND		NV	0.01
PERYLENE	4	0	0	ND	ND	ND	ND		NV	NV
INDENO(1,2,3-C,D)PYRENE	4	0	0	ND	ND	ND	ND		NV	NV
DIBENZO(a,h)ANTHRACENE	4	0	0	ND	ND	ND	ND		NV	NV
BENZO(g,h,i)PERYLENE	4	0	0	ND	ND	ND	ND		NV	NV
TOTAL PAHs	4	2	50	1.26	2.16	0.20	5.00	A1-1	NV	NV

NV: No value.
ND: Not detected.

PWQO: Provincial Water Quality Objective (unless otherwise noted).
MAC: Maximum Acceptable Concentration (unless otherwise noted).

* EPA Federal Register (1976).
† WHO (1984).
‡ IJC (1978).

* - for calculation of average and standard deviation, concentrations which are non-detectable are assumed to be zero
‡ - minimum or maximum detectable concentration

Table 3.18: SUMMARY OF SITE PERIMETER SHALLOW GROUNDWATER CHEMISTRY

PARAMETER	Number Samples	Number Detects	Detection Frequency	Average Conc.*	Standard Deviation*	Minimum Conc.‡	Maximum Conc.‡	Location of Maximum	Water Criteria PWQO	MAC
pH	42	42	100	10.9	2.2	7.0	12.9	D4	6.5-8.5	NV
SPECIFIC CONDUCTANCE (µS/cm)	42	42	100	3122	1819	900	7950	D4	NV	NV
TEMPERATURE (C)	39	39	100	9.1	2.7	1.0	15.0	B2-2	NV	NV
DISSOLVED OXYGEN	28	19	68	2.5	2.6	0.5	9.0	D6	NV	NV
DIC	4	4	100	13.18	16.12	2.50	41.00	B2-2	NV	NV
ALKALINITY	33	33	100	364.24	218.61	68.00	760.00	B5	NV	NV
SULPHIDE	4	2	50	2.71	4.67	0.05	10.80	D3-2	NV	NV
TOTAL CYANIDE	26	19	73	0.243	0.569	0.004	2.600	D3-2	0.005	0.2
BROMIDE	43	6	14	0.12	0.35	0.20	1.40	B2-2	NV	NV
CHLORIDE	43	43	100	103.72	75.50	7.50	290.00	B4-2	NV	NV
FLUORIDE	43	39	91	0.94	0.70	0.20	3.20	D5-2	NV	1.5
SULPHATE	43	43	100	527.37	881.27	16.60	3500.00	D5-2	NV	500
NITRATE-N	43	5	12	0.05	0.17	0.20	1.00	D5-2	NV	10
AMMONIA-N	3	3	100	4.13	0.98	3.00	5.40	D3-2	0.02	NV
TOTAL KJELDAHL NITROGEN	13	13	100	4.96	6.79	1.13	28.00	D5-2	NV	NV
TOTAL PHOSPHOROUS	11	10	91	0.20	0.40	0.00	1.37	D5-2	0.03	NV
DOC	29	29	100	9.42	8.31	3.20	32.00	D6	NV	NV
PHENOLS	43	40	93	0.011	0.017	0.001	0.080	D3-2	0.001	NV
PCB (µg/L)	6	0	0	ND	ND	ND	ND		0.001	NV
OIL AND GREASE	10	9	90	3.10	2.02	1.00	7.00	D6	NV	NV
ZINC	34	20	59	0.01	0.02	0.01	0.10	B2-2	0.03	NV
CADMIUM	34	12	35	0.0006	0.0020	0.0002	0.0120	D4	0.000	0.005
MANGANESE	34	14	41	0.44	1.09	0.01	5.20	D5-2	NV	NV
COBALT	34	15	44	0.01	0.01	0.01	0.03	D4,B4-2,B5&D5-2	NV	NV
COPPER	34	14	41	0.003	0.004	0.005	0.015	D5-2	0.005	NV
IRON	34	28	82	7.03	23.53	0.02	132.00	D5-2	0.3	NV
LEAD	34	0	0	ND	ND	ND	ND		0.025	0.05
CHROMIUM	34	23	68	0.01	0.01	0.01	0.04	D5-2	0.1	0.05
NICKEL	34	14	41	0.01	0.01	0.01	0.02	D4,B5,D1-2,D6,D5-2	0.025	0.00134*
BERYLLIUM	24	0	0	ND	ND	ND	ND		NV	NV
MOLYBDENUM	24	14	58	0.02	0.02	0.02	0.08	D5-2	NV	NV
CALCIUM	33	33	100	265.58	167.28	68.00	760.00	D5-2	NV	NV
VANADIUM	24	18	75	0.03	0.02	0.03	0.06	D2	NV	NV
ALUMINUM	24	24	100	0.42	0.16	0.20	0.80	D3-2	0.15	0.2†
MAGNESIUM	33	32	97	17.06	32.76	0.05	117.00	D6	NV	NV
BARIUM	24	24	100	0.15	0.11	0.06	0.60	B3	NV	1
POTASSIUM	33	33	100	147.45	219.68	3.10	820.00	D5-2	NV	NV
STRONTIUM	24	24	100	1.02	0.71	0.27	3.30	D5-2	NV	NV
SODIUM	33	33	100	74.02	67.99	6.00	280.00	D5-2	NV	NV
ARSENIC (µg/L)	3	3	100	5	2	4	8	D3-2	100	50
SELENIUM (µg/L)	3	2	67	2	1	2	3	D3-2	100	10
MERCURY (µg/L)	3	2	67	0.09	0.06	0.12	0.15	D3-2	0.2	1
BTX (µg/L)										
BENZENE	12	5	42	9.3	17.8	2.0	62.0	D6	NV	5
TOLUENE	12	5	42	5.9	8.6	2.0	22.0	B5	NV	NV
XYLENE	12	2	17	3.1	6.9	18.0	19.0	D2	NV	NV
TOTAL BTX	12	7	58	18.4	24.5	2.0	65.0	D2	NV	NV
PAHs (µg/L)										
NAPHTHALENE	26	19	73	6.04	12.35	0.10	45.00	D3-2	NV	NV
ACEPHTHYLENE	26	15	58	0.30	0.57	0.08	2.30	D3-2	NV	NV
ACEPHTHENE	26	23	88	0.98	0.85	0.10	2.90	D4	NV	NV
FLUORENE	26	24	92	0.66	0.67	0.10	2.40	B3	NV	NV
PHENTHRENE	26	22	85	1.61	1.33	0.06	4.70	B3	NV	NV
ANTHRACENE	26	18	69	0.39	0.78	0.10	4.10	D3-2	NV	NV
FLUORANTHENE	26	22	85	1.28	1.11	0.04	3.40	B3	NV	NV
PYRENE	26	21	81	1.15	0.99	0.04	3.10	B5	NV	NV
BENZO(a)ANTHRACENE	26	12	46	0.13	0.18	0.02	0.60	D2	NV	NV
CHRYSENE	26	15	58	0.17	0.21	0.03	0.70	D2	NV	NV
BENZO(b)FLUORANTHENE	26	6	23	0.13	0.32	0.10	1.50	D2	NV	NV
BENZO(k)FLUORANTHENE	26	3	12	0.04	0.12	0.20	0.50	B4-2	NV	NV
BENZO(a)PYRENE	26	5	19	0.13	0.33	0.10	1.40	D2	NV	0.01
PERYLENE	26	3	12	0.01	0.03	0.10	0.10	B4-2	NV	NV
INDENO(1,2,3-C,D)PYRENE	26	3	12	0.03	0.09	0.20	0.40	B4-2	NV	NV
DIBENZO(a,h)ANTHRACENE	26	0	0	ND	ND	ND	ND		NV	NV
BENZO(g,h,i)PERYLENE	26	1	4	0.02	0.10	0.50	0.50	B4-2	NV	NV
TOTAL PAHs	26	24	92	13.07	14.37	0.70	61.05	D3-2	NV	NV

NV: No value.
ND: Not detected.

PWQO: Provincial Water Quality Objective (unless otherwise noted).
MAC: Maximum Acceptable Concentration (unless otherwise noted).

* EPA Federal Register (1976).
† WHO (1984).
‡ IJC (1978).

* - for calculation of average and standard deviation, concentrations which are non-detectable are assumed to be zero.
‡ - minimum and maximum detectable concentration.

Table 3.19: SUMMARY OF SITE PERIMETER DEEP GROUNDWATER CHEMISTRY

PARAMETER	Number	Number	Detection	Average	Standard	Minimum	Maximum	Location of	Water Criteria	
	Samples	Detects	Frequency	Conc.*	Deviation*	Conc.‡	Conc.‡	Maximum	PWQO	MAC
pH	22	22	100	8.5	1.2	7.1	11.7	B2-1	6.5-8.5	NV
SPECIFIC CONDUCTANCE (µS/cm)	22	22	100	1744	1735	190	5950	D3-1	NV	NV
TEMPERATURE (C)	22	22	100	9.3	2.0	5.0	13.0	D1-1	NV	NV
DISSOLVED OXYGEN	16	15	94	3.6	2.1	0.5	8.0	B4-1	NV	NV
DIC	1	1	100	8.00	0.00	8.00	8.00	B2-1	NV	NV
ALKALINITY	18	18	100	68.17	41.60	10.00	139.00	D1-1	NV	NV
SULPHIDE	1	0	0	ND	ND	ND	ND		NV	NV
TOTAL CYANIDE	17	2	12	0.055	0.219	0.008	0.930	D5-1	0.005	0.2
BROMIDE	22	5	23	1.78	3.79	1.00	12.00	D3-1	NV	NV
CHLORIDE	22	22	100	382.54	537.78	11.10	1530.00	D5-1	NV	NV
FLUORIDE	22	22	100	0.68	0.63	0.04	2.00	D5-1	NV	1.5
SULPHATE	22	22	100	148.92	242.82	11.50	970.00	D5-1	NV	500
NITRATE-N	22	13	59	0.31	0.56	0.02	2.50	D3-1	NV	10
AMMONIA-N	0	0	0	ND	ND	ND	ND		0.02	NV
TOTAL KJELDÄHL NITROGEN	7	7	100	0.45	0.42	0.09	1.17	D1-1	NV	NV
TOTAL PHOSPHOROUS	6	6	100	1.85	2.03	0.22	6.10	B4-1	0.03	NV
DOC	11	8	73	3.49	4.67	0.50	14.00	D1-1	NV	NV
PHENOLS	22	14	64	0.003	0.004	0.001	0.015	B4-1	0.001	NV
PCB (µg/L)	3	1	33	0.004	0.006	0.012	0.012	D1-1	0.001	NV
OIL AND GREASE	4	3	75	2.25	1.48	2.00	4.00	D1-1	NV	NV
ZINC	16	10	63	0.01	0.01	0.01	0.04	D5-1	0.03	NV
CADMIUM	16	5	31	0.0004	0.0007	0.0004	0.0026	D1-1	0.0002	0.005
MANGANESE	16	10	63	1.33	1.91	0.08	5.60	D1-1	NV	NV
COBALT	16	7	44	0.01	0.01	0.01	0.04	D3-1	NV	NV
COPPER	16	10	63	0.006	0.007	0.005	0.030	B4-1	0.005	NV
IRON	16	14	88	9.44	19.24	0.04	63.00	D5-1	0.3	NV
LEAD	16	0	0	ND	ND	ND	ND		0.025	0.05
CHROMIUM	16	8	50	0.01	0.01	0.01	0.03	D3-1	0.1	0.05
NICKEL	16	7	44	0.01	0.01	0.01	0.04	D3-1	0.025	0.00134*
BERYLLIUM	12	0	0	ND	ND	ND	ND		NV	NV
MOLYBDENUM	12	5	42	0.07	0.11	0.04	0.36	D3-1	NV	NV
CALCIUM	18	18	100	158.57	150.35	11.30	460.00	D3-1	NV	NV
VANADIUM	12	6	50	0.01	0.01	0.01	0.03	D3-1	NV	NV
ALUMINUM	12	12	100	0.47	0.76	0.04	2.90	B4-1	0.1‡	0.2†
MAGNESIUM	18	18	100	17.91	15.75	0.45	45.00	D3-1	NV	NV
BARIUM	12	12	100	0.12	0.10	0.03	0.33	D3-1	NV	1
POTASSIUM	18	18	100	16.07	13.93	2.50	53.00	B2-1	NV	NV
STRONTIUM	12	12	100	2.70	3.62	0.11	10.70	D3-1	NV	NV
SODIUM	18	18	100	89.88	104.52	6.00	290.00	D3-1	NV	NV
ARSENIC (µg/L)	0	0	0	ND	ND	ND	ND		100	50
SELENIUM (µg/L)	0	0	0	ND	ND	ND	ND		100	10
MERCURY (µg/L)	0	0	0	ND	ND	ND	ND		0.2	1
BTX (µg/L)										
BENZENE	8	2	25	2.8	5.2	7.0	15.0	D5-1	NV	5
TOLUENE	8	2	25	3.5	6.2	11.0	17.0	D5-1	NV	NV
XYLENE	8	1	13	0.3	0.7	2.0	2.0	B2-1	NV	NV
TOTAL BTX	8	4	50	6.5	10.4	2.0	32.0	D5-1	NV	NV
PAHs (µg/L)										
NAPHTHALENE	14	2	14	0.03	0.07	0.20	0.21	B2-1	NV	NV
ACEPHTHYLENE	14	0	0	ND	ND	ND	ND		NV	NV
ACEPHTHENE	14	1	7	0.00	0.00	0.01	0.01	B2-1	NV	NV
FLUORENE	14	2	14	0.01	0.03	0.03	0.10	B2-1	NV	NV
PHENTHRENE	14	2	14	0.01	0.03	0.04	0.10	B4-1	NV	NV
ANTHRACENE	14	0	0	ND	ND	ND	ND		NV	NV
FLUORANTHENE	14	4	29	0.26	0.79	0.10	3.10	B2-1	NV	NV
PYRENE	14	5	36	0.11	0.20	0.10	0.77	B2-1	NV	NV
BENZO(a)ANTHRACENE	14	1	7	0.08	0.27	1.06	1.06	B2-1	NV	NV
CHRYSENE	14	1	7	0.22	0.80	3.10	3.10	B2-1	NV	NV
BENZO(b)FLUORANTHENE	14	1	7	0.38	1.36	5.30	5.30	B2-1	NV	NV
BENZO(k)FLUORANTHENE	14	1	7	0.04	0.13	0.49	0.49	B2-1	NV	NV
BENZO(a)PYRENE	14	1	7	0.13	0.46	1.80	1.80	B2-1	NV	0.01
PERYLENE	14	1	7	0.05	0.16	0.63	0.63	B2-1	NV	NV
INDENO(1,2,3-C,D)PYRENE	14	1	7	0.13	0.46	1.80	1.80	B2-1	NV	NV
DIBENZO(a,h)ANTHRACENE	14	1	7	0.07	0.25	0.97	0.97	B2-1	NV	NV
BENZO(g,h,i)PERYLENE	14	1	7	0.08	0.29	1.11	1.11	B2-1	NV	NV
TOTAL PAHs	14	7	50	1.57	5.23	0.10	20.42	B2-1	NV	NV

NV: No value.
ND: Not detected.

PWQO: Provincial Water Quality Objective (unless otherwise noted).
MAC: Maximum Acceptable Concentration (unless otherwise noted).

* EPA Federal Register (1976).
† WHO (1984).
‡ IJC (1978).

- for calculation of average and standard deviation, concentrations which are non-detectable are assumed to be zero
‡ - minimum or maximum detectable concentration

Table 3.20: SUMMMARY OF GROUNDWATER CHEMISTRY CHEMISTRY AT WELLS
A7-1, C4 AND D3-2

	A7-1		C4		D3-2	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
pH	8.6	0.6	8.7	0.4	11.7	0.2
SPECIFIC CONDUCTANCE ($\mu\text{S}/\text{cm}$)	193	12	1631	1052	1350	363
TEMPERATURE ($^{\circ}\text{C}$)	10.3	2.6	9.0	3.0	9.3	2.3
DISSOLVED OXYGEN	6.5	0.0	3.8	1.4	1.1	1.5
DIC	11.1	2.1	51.5	17.2	3.9	1.5
ALKALINITY	45	4	201	73	116	28
SULPHIDE	ND	ND	10.68	15.08	3.62	5.08
TOTAL CYANIDE	ND	ND	0.048	0.019	1.665	0.681
BROMIDE	ND	ND	ND	ND	ND	ND
CHLORIDE	12.3	1.3	385.0	82.0	13.0	3.4
FLUORIDE	0.07	0.04	1.68	0.42	0.77	0.23
SULPHATE	10.5	0.9	257.5	36.3	342.5	69.1
NITRATE-N	0.33	0.28	ND	ND	ND	ND
AMMONIA-N	0.296	0.259	0.147	0.092	4.133	0.984
TOTAL KJELDAHL NITROGEN	ND	ND	0.69	0.08	5.13	0.86
TOTAL PHOSPHOROUS	ND	ND	0.045	0.038	0.019	0.005
DOC	0.2	0.2	26.3	3.2	9.5	3.0
PHENOLS	ND	ND	0.004	0.002	0.057	0.022
PCB ($\mu\text{g}/\text{L}$)	ND	ND	ND	ND	ND	ND
OIL AND GREASE	ND	ND	NA	NA	NA	NA
ZINC	ND	ND	0.04	0.03	ND	ND
CADMIUM	0.0003	0.0004	0.0001	0.0002	0.0003	0.0005
MANGANESE	0.08	0.04	0.32	0.11	ND	ND
COBALT	ND	ND	ND	ND	0.00	0.00
COPPER	ND	ND	0.004	0.004	ND	ND
IRON	0.17	0.12	0.24	0.13	0.67	0.21
LEAD	ND	ND	ND	ND	ND	ND
CHROMIUM	ND	ND	ND	ND	ND	ND
NICKEL	ND	ND	ND	ND	ND	ND
BERYLLIUM	ND	ND	ND	ND	ND	ND
MOLYBDENUM	ND	ND	0.06	ND	0.03	0.02
CALCIUM	18	3	70	11	152	33
VANADIUM	ND	ND	ND	0.01	0.04	0.01
ALUMINUM	0.03	0.01	0.11	0.05	0.63	0.17
MAGNESIUM	4.4	0.3	59.4	17.4	0.2	0.2
BARIUM	0.02	0.01	0.04	0.01	0.09	0.02
POTASSIUM	1.20	0.05	48.75	3.27	77.00	22.44
STRONTIUM	0.07	0.01	0.38	0.05	0.68	0.15
SODIUM	4	ND	239	42	28	6
ARSENIC ($\mu\text{g}/\text{L}$)	1	1	6	2	3	2
SELENIUM ($\mu\text{g}/\text{L}$)	ND	ND	ND	ND	1	1
MERCURY ($\mu\text{g}/\text{L}$)	0.1	0.1	0.2	0.1	0.1	0.1

...continued

Table 3.20: SUMMARY OF GROUNDWATER CHEMISTRY CHEMISTRY AT WELLS
A7-1, C4 AND D3-2

	A7-1		C4		D3-2	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
BTX (µg/L)						
BENZENE	ND	ND	77	108	1	1
TOLUENE	ND	ND	19	27	ND	ND
XYLENE	ND	ND	64	88	ND	ND
TOTAL BTX	ND	ND	160	223	1	1
PAHs (µg/L)						
NAPHTHALENE	ND	ND	5.8	9.4	34.0	7.6
ACENAPHTHYLENE	ND	ND	4.3	4.9	1.5	0.7
ACENAPHTHENE	ND	ND	1.4	1.4	0.6	0.2
FLUORENE	ND	ND	3.3	3.1	0.8	0.3
PHENANTHRENE	ND	ND	3.2	4.5	1.7	0.5
ANTHRACENE	ND	ND	1.2	0.7	1.0	1.5
FLUORANTHENE	ND	ND	3.3	2.3	1.0	0.4
PYRENE	ND	ND	2.1	1.3	1.0	0.5
BENZO(a)ANTHRACENE	ND	ND	0.5	0.4	0.1	0.2
CHRYSENE	ND	ND	0.6	0.5	0.1	0.1
BENZO(b)FLUORANTHENE	ND	ND	0.3	0.4	0.1	0.1
BENZO(k)FLUORANTHENE	ND	ND	0.3	0.3	0.1	0.1
BENZO(a)PYRENE	ND	ND	0.3	0.3	0.1	0.2
PERYLENE	ND	ND	0.1	0.1	ND	ND
INDENO(1,2,3-C,D)PYRENE	ND	ND	0.2	0.2	0.1	0.1
DIBENZO(a,h)ANTHRACENE	ND	ND	0.0	0.1	ND	ND
BENZO(g,h,i)PERYLENE	ND	ND	0.1	0.2	ND	ND
TOTAL PAHs	ND	ND	27.0	24.2	42.2	11.6

* All Units are mg/L unless otherwise specified.

NA Not Analyzed

ND Not Detected

TABLE 3.21: ESTIMATED MASS FLUX TO ON-SITE CREEKS AND ST. MARYS RIVER

	MASS FLUX (kg/day)					
Surface Water Body	St. Marys River	Baseline Road Ditch	Bennett Creek	Spring Creek	West Davignon Diversion	Total Off-Site Flux Via Groundwater
<u>Parameter</u>						
Chloride	6.0x10 ¹	7.0	9.1x10 ⁻¹	1.4	9.3x10 ⁻²	6.9x10 ¹
Fluoride	4.6x10 ⁻¹	1.3x10 ⁻¹	2.3x10 ⁻²	1.1x10 ⁻²	1.2x10 ⁻³	6.3x10 ⁻¹
Sulphate	2.1x10 ²	2.0x10 ¹	1.2	2.9	7.7x10 ⁻¹	2.4x10 ²
Total Cyanide	1.2x10 ⁻¹	8.0x10 ⁻⁴	ND	9.9x10 ⁻⁵	8.2x10 ⁻⁵	1.2x10 ⁻¹
Nitrate-N	2.1x10 ⁻²	1.4x10 ⁻²	2.5x10 ⁻³	1.2x10 ⁻¹	2.2x10 ⁻⁵	1.6x10 ⁻¹
TKN	2.3	1.9	4.7x10 ⁻²	1.8x10 ⁻¹	6.3x10 ⁻³	4.4
Total Phosphorus	9.9x10 ⁻²	1.1x10 ⁻²	3.4x10 ⁻³	4.9x10 ⁻³	2.5x10 ⁻⁴	1.2x10 ⁻¹
Phenols	6.8x10 ⁻³	1.4x10 ⁻²	1.8x10 ⁻⁴	6.6x10 ⁻³	3.0x10 ⁻⁶	2.8x10 ⁻²
BTX	1.3x10 ⁻²	ND*	3.3x10 ⁻³	4.3x10 ⁻¹	3.5x10 ⁻⁵	4.4x10 ⁻¹
PAH	7.7x10 ⁻³	1.3x10 ⁻³ *	1.6x10 ⁻⁴	5.2x10 ⁻¹	9.7x10 ⁻⁷	5.3x10 ⁻¹
<u>Metals</u>						
Zinc	4.9x10 ⁻³	2.7x10 ⁻³	3.5x10 ⁻⁴	ND	1.8x10 ⁻⁵	7.9x10 ⁻³
Cadmium	3.9x10 ⁻⁴	2.1x10 ⁻⁴	1.4x10 ⁻⁵	5.9x10 ⁻⁵	1.9x10 ⁻⁷	6.7x10 ⁻⁴
Manganese	8.8x10 ⁻²	1.7x10 ⁻¹	9.2x10 ⁻³	1.8x10 ⁻²	1.5x10 ⁻³	2.9x10 ⁻¹
Cobalt	6.0x10 ⁻³	8.9x10 ⁻⁴	ND	ND	8.9x10 ⁻⁶	6.9x10 ⁻³
Copper	1.3x10 ⁻³	1.6x10 ⁻³	6.5x10 ⁻⁴	ND	4.5x10 ⁻⁶	3.5x10 ⁻³
Iron	1.5	1.9	8.7x10 ⁻³	7.6x10 ⁻²	2.3x10 ⁻²	3.5

... continued

TABLE 3.21:

ESTIMATED MASS FLUX TO ON-SITE CREEKS AND ST. MARYS RIVER

Surface Water Body	MASS FLUX (kg/day)					Total Off-Site Flux Via Groundwater
	St. Marys River	Baseline Road Ditch	Bennett Creek	Spring Creek	West Davignon Diversion	
<u>Parameter</u>						
Chromium	8.1×10^{-3}	2.1×10^{-3}	ND	ND	1.5×10^{-5}	1.0×10^{-2}
Nickel	3.0×10^{-3}	3.5×10^{-4}	ND	ND	1.0×10^{-5}	3.4×10^{-3}
Molybdenum	1.3×10^{-2}	3.9×10^{-3} *	1.3×10^{-4}	ND	1.9×10^{-5}	1.7×10^{-2}
Calcium	1.6×10^2	2.2×10^1	4.7	3.7	2.6×10^{-1}	1.9×10^2
Vanadium	2.0×10^{-2}	2.4×10^{-3} *	7.8×10^{-4}	ND	2.8×10^{-5}	2.3×10^{-2}
Aluminum	2.4×10^{-1}	8.0×10^{-2} *	2.1×10^{-2}	1.4×10^{-2}	2.8×10^{-4}	3.6×10^{-1}
Magnesium	2.4	2.7	7.4×10^{-1}	1.8×10^{-1}	6.6×10^{-2}	6.1
Barium	1.1×10^{-1}	1.0×10^{-2} *	3.5×10^{-3}	4.9×10^{-3}	5.8×10^{-5}	1.3×10^{-1}
Potassium	7.0×10^1	2.3	1.9×10^{-1}	5.4×10^{-1}	1.5×10^{-1}	7.3×10^1
Strontium	6.1×10^{-1}	1.1×10^{-1}	1.8×10^{-2}	7.9×10^{-3}	9.5×10^{-4}	7.5×10^{-1}
Sodium	3.4×10^1	1.3×10^1	1.3	1.5	1.1×10^{-1}	5.0×10^1

ND - weighted average concentration is not detectable. No measurable flux.

* - may not be representative, parameter not analysed for at all wells.

... continued

TABLE 4.1: SCHEDULE OF MINI-PIEZOMETER SAMPLING

Mini-Piezometer	Analytical Level ¹			
	Summer 1988	Fall 1988	Winter 1989	Spring 1989
Site A				
SP-A1	2	NS	NS	NS
SP-A2	3	*	NS	2+PAH, BTX
SP-A3	2	NS	NS	NS
Site B				
SP-B1	1+PAH	*	NS	NS
Site 1				
SP-P30	1	NS	NS	NS
SP-P46	1	NS	NS	NS
SP-P47	3	*	NS	NS
SP-48	1	NS	NS	NS
SP-49	1	NS	NS	NS
SP-50	1	NS	NS	NS
SP-51	1	NS	NS	NS
SP-52	1	NS	NS	NS

¹ - see Table 3.2 for list of analyses for each level.

* - field measurements, DIC, total CN, anions, TKN, total phosphorus, Ca, Mg, Na, K, BTX, PAH.

TABLE 4.2: SUMMARY OF RIVER BED LOCATIONS WITH ELEVATED ELECTRICAL CONDUCTANCES

Site No. or Shoreline Reference No.	Distance Offshore (m)	Comments
Site 1	0-100	Anomaly is 250 m long
Site C	10, 20	
Site B	10	Anomaly occurs at base of slag
Site A	10	
SR 4.5	20	
SR 7.5	20	
SR 17.3	10	Anomaly occurs at base of slag

TABLE 4.3: SUMMARY OF RIVER BED MINI-PIEZOMETER WATER LEVELS AND VERTICAL GRADIENTS

Site No.	Piezometer No.	Screen Depth (m)	Water Level Relative to River (cm)		Vertical Gradient**	
			July 88	Oct. 88	July 88	Oct. 88
A	SP-A1	1	-0.5	+3	-0.005	+0.03
	SP-A2	0.75	-	+7	-	+0.09
	SP-A3	0.80	-	+3	-	+0.04
	SP-A6	1	-	-	-	-
B	SP-B1	2.8	±1*	+15	-	+0.05
1	SP-P30	1.3	+6.0	+18	+0.046	+0.14
	SP-P46	1.3	+6.0	+6.5	+0.046	+0.05
	SP-P47	2.3	+4.0	+16	+0.017	+0.07
	SP-P48	2.3	+8.5	+17	+0.037	+0.07
	SP-P49	2.3	+9.5	+20	+0.041	+0.09
	SP-P50	2.3	+4.7	+10	+0.020	+0.04
	SP-P51	2.3	+7.7	+15	+0.033	+0.06
	SP-P52	2.0	+9.0	+25	+0.045	+0.12

- not measured.

* not obviously different.

** vertical gradients (+) upwards, (-) downwards.

TABLE 4.4: SPECIFIC DISCHARGE VALUES FOR ST. MARYS RIVER SEEPAGE STUDY

Site	Seepage Meter No.	Seepage Meter Method			Darcy Equation ¹		
		Volume of Water Displaced (L)	Time (hr)	Specific Discharge (m/yr)	Hydraulic Conductivity (m/s)	Average Gradient	Specific Discharge (m/yr)
1	A	0.10	0.37	1.6x10 ¹	6x10 ⁻⁵	0.08	1.5x10 ²
		0.34	0.23	8.5x10 ¹			
	B	0.125	0.37	1.9x10 ¹			
		0.25	0.23	6.3x10 ¹			
	C	0.35	0.37	5.4x10 ¹			
		0.25	0.23	6.3x10 ¹			
	D	0.12	0.37	1.9x10 ¹			
		0.69	0.23	1.7x10 ²			
	SM34	1.05	2.67	2.3x10 ¹			
		0.11	0.50	1.3x10 ¹			
AVERAGE				5.2x10 ¹			
A	F	0.06	2.33	1.5	5x10 ⁻⁶	0.05	7.9
	G	0.09	2.5	2.1			
	I	0.02	2.5	4.6x10 ⁻¹			
	J	0.22	2.1	6.0			
	AVERAGE						

¹ Based on Equation 4.1.

TABLE 4.5: COMPARISON OF GROUNDWATER AND SEEPAGE FLUXES

Parameter	Site Number	
	A	1
<u>Seepage Water Method¹</u>		
Specific Discharge, q (m/yr)	5.2×10^1	2.5
Length, L (m)	10	10
Width, W (m)	10	100
Volumetric Flux, Q (m ³ /yr)	5.2×10^3	2.5×10^3
<u>Groundwater Method²</u>		
Hydraulic Conductivity, k (m/s)	1.9×10^{-6}	1.9×10^{-6}
Hydraulic Gradient, i (-)	0.012	0.012
Length, L (m)	10	10
Thickness, b (m)	5	9
Volumetric Flux, Q (m ³ /yr)	3.6×10^1	6.5×10^1

¹ - Based on Equation 4.2

² - Based on Equation 4.3

TABLE 4.6: RANGE OF ANALYTICAL PARAMETERS FOR RIVER BED CORES

	Core Identification			Dredge Disposal Guideline
	B	A4	A5	
Core Depth (m)	0-2.7	0-0.30	0-0.70	
pH (pH units)	10.6-6.7	9.2-8.7	11.1-10.6	
Sp. Conductance ($\mu\text{S}/\text{cm}$)	406-47	370-297	1,460-548	
Loss on Ignition (%)	12.5-0.40	0.81-0.49	3.1-1.38	
Moisture Content (%)	51-16.1	15.1-13.8	23-15.6	
Phenols	1.2-<0.5	<0.5	<0.5	
Oil and Grease	6,200-52	150-45	550-98	
Total Phosphorus	720-110	400-340	700-580	
Bromide	<2	NA	<2	
Chloride	23-5.3	NA	26-16.5	
Fluoride	5.5-3.5	NA	19.4-2.7	
Nitrate-N	1.08-<0.5	NA	1.6-<0.2	
Ammonia-N	29-12	7	14-9	
TKN	1,320-168	260-44	42-23	
Sulphate	185-68	NA	560-184	
Metals				
Zinc	760-6	35-15	65-31	100
Cadmium	0.95-<0.05	0.05-<0.05	<0.05	1
Manganese	14,100-54	1,560-450	34,000-3,600	
Cobalt	19-2	5-4	17-8	
Copper	59-3	11-7	36-12	25
Iron	95,000-5,100	15,500-10,800	144,000-32,000	10,000
Lead	195-2	10-4	92-8	50
Chromium	260-6	34-15	430-60	25
Nickel	44-4	8-5	47-12	25
Beryllium	2-<1	<1	1	
Molybdenum	8-<2	<2	12-10	
Calcium	56,000-1,100	26,000-5,000	97,000-65,000	
Vanadium	127-15	35-28	210-160	
Aluminum	14,600-2,600	12,000-5,100	11,100-9,800	
Magnesium	15,600-900	4,000-2,200	21,000-15,900	
Barium	89-10	33-20	58-42	
Potassium	1,920-400	1,030-870	980-830	
Strontium	71-6	28-16	76-54	
Sodium	1,670-165	530-330	1,920-1,470	
Total PAH	288-0.013	3.4-0.6	25.3-24.2	

Concentration units are $\mu\text{g}/\text{g}$ unless otherwise specified.

TABLE 4.7:

COMPARISON OF SEEPAGE WATER AND GROUNDWATER AT
SEEPAGE STUDY SITE A

Parameter	Water Chemistry		
	Seepage Water Range ¹	Average Shallow Groundwater ²	Average Deep Groundwater ³
pH (pH units)	8.2-11.9	12.6	8.3
Sp. Conductance ($\mu\text{S}/\text{cm}$)	1,100-4,850	5,882	4,800
DIC	9-34	NA	NA
Alkalinity	35-490	670	11
Sulphide	<0.05-0.02	NA	NA
Total CN	<0.002-0.007	0.0325	<0.005
Total P	0.015-0.017	0.0001*	0.03
Bromide	<3	<5	8
Chloride	74-116	53	1,450
Fluoride	0.3-1.2	0.4	1.2
Nitrate-N	<0.1-6.5	<1	0.6
Ammonia-N	4.2*	NA	NA
TKN	2.9-6.3	1.43*	0.3
Sulphate	230-610	1,022	27
DOC	5-7	6.3	1.1
Phenols	0.005-0.027	0.013	<0.001
Oil and Grease	NA	5*	2
Total PAH ($\mu\text{g}/\text{L}$)	0.36-16.7	15.1	<3
Total BTX ($\mu\text{g}/\text{L}$)	<5	<30	11
Metals			
Zinc	<0.01	0.003	0.02
Cadmium	0.0006-0.0010	0.004	0.0001
Manganese	<0.01-0.30	<0.01	0.12
Cobalt	<0.01-0.01	0.01	0.04
Copper	<0.005	<0.005	0.005
Iron	0.02-0.10	0.02	0.41
Lead	<0.05	<0.05	<0.05
Chromium	<0.01-0.02	0.03	0.03
Nickel	<0.01-0.01	0.01	0.03
Beryllium	<0.01	<0.01	<0.01
Molybdenum	0.02-0.06	0.03	0.30
Calcium	87-270	553	427
Vanadium	<0.01-0.04	0.05	0.01
Aluminum	0.16-0.48	0.40	0.64
Magnesium	0.25-6.0	0.90	43
Barium	0.08-0.19	0.08	0.33
Potassium	18.3-240	393	29
Strontium	0.47-1.26	1.6	10.3
Sodium	80-129	113	290
Arsenic ($\mu\text{g}/\text{L}$)	11*	NA	NA
Selenium ($\mu\text{g}/\text{L}$)	<1*	NA	NA
Mercury ($\mu\text{g}/\text{L}$)	<0.05*	NA	NA

All units are mg/L unless otherwise specified.

¹ - mini-piezometers SP-A1, SP-A2 and SP-A3² - monitoring well D4³ - monitoring well D3-1

* only one sample analysed

NA - not analysed

TABLE 4.8:

COMPARISON OF SEEPAGE WATER AND GROUNDWATER AT
SEEPAGE STUDY SITE B

Parameter	Water Chemistry		
	Seepage Water Range ¹	Average Shallow Groundwater ²	Average Deep Groundwater ³
pH (pH units)	6.9-7.0	12.5	9.8
Sp. Conductance ($\mu\text{S}/\text{cm}$)	460-470	3,590	255
Alkalinity	171*	465	43
Total Cyanide	<0.002*	0.02	<0.005
Bromide	<1	<5	<0.1
Chloride	1.86-470	152	28
Fluoride	0.06-<0.5	0.52	0.23
Nitrate-N	<0.01*	0.10	0.04
Sulphate	0.10-310	35	18
DOC	1.5*	4.0	0.65
Phenol	<0.001*	0.003	0.004
Oil and Grease	4*	<1	<1
Total BTX ($\mu\text{g}/\text{L}$)	<5*	2*	<5*
Total PAH ($\mu\text{g}/\text{L}$)	<3-0.47	11.7	0.45
Metals			
Zinc	0.01*	<0.01	0.01
Cadmium	0.0008*	<0.005	<0.005
Manganese	0.36*	0.01	0.04
Cobalt	<0.01*	0.01	<0.01
Copper	<0.005*	<0.005	0.01
Iron	9.1*	0.04	0.8
Lead	<0.05*	<0.05	<0.05
Chromium	<0.01*	0.01	<0.01
Nickel	<0.01*	<0.01	<0.01
Calcium	300	230	31
Magnesium	51	0.16	2.7
Potassium	6.1	46	3.2
Sodium	58	34	8.2

All units are mg/L unless otherwise specified.

¹ - mini-piezometer SP-B1² - monitoring well B4-2³ - monitoring well B4-1

* only one sample analysed

TABLE 4.9:

COMPARISON OF SEEPAGE WATER AND GROUNDWATER AT
SEEPAGE STUDY SITE 1

Parameter	Water Chemistry		
	Seepage Water Range ¹	Average Shallow Groundwater ²	Average Deep Groundwater ³
pH (pH units)	7.0-8.0	12.5	7.4
Sp. Conductance (µS/cm)	860-2,690	4,498	1,940
Alkalinity	169*	675	132
Sulphide	<0.05*	NA	NA
Total Cyanide	<0.002	0.05	<0.005
Bromide	<0.5-2	<1	<1
Chloride	1.67-550	128	382
Fluoride	<0.2-0.5	0.7	0.8
Nitrate-N	<0.1-0.4	0.03	<0.2
Sulphate	154-300	86	202
DOC	14.5-31	3.9	13
Phenol	<0.001-0.001	0.010	0.001
Oil and Grease	2-4	2	4*
Total Kjeldahl Nitrogen	0.25-1.62	3.20*	1.17*
Total Phosphorus	0.005-0.112	<0.001*	0.22*
Total BTX (µg/L)	<5*	42	7
Total PAH (µg/L)	<3*	11.1	0.22
Metals			
Zinc	<0.01-0.2	0.01	0.02
Cadmium	0.0002-0.0016	<0.005	0.001
Manganese	<0.01-5.4	0.01	4.9
Cobalt	<0.01-0.02	0.005	0.01
Copper	<0.005-0.045	0.03	0.007
Iron	<0.02-0.02	<0.05	0.7
Lead	<0.05	0.02	<0.05
Chromium	<0.01-0.02	0.01	0.02
Nickel	<0.01-0.01	<0.01	0.01
Beryllium	<0.01*	<0.01	<0.01
Molybdenum	0.04*	0.04	0.02
Calcium	57-290	350	227
Vanadium	0.02*	0.02	0.02
Aluminum	0.36*	0.45	0.25
Magnesium	10.5-50	0.15	26
Barium	0.08*	0.20	0.11
Potassium	2.2-5.8	54	28
Strontium	1.16*	1.18	1.34
Sodium	10.5-54	44	63
Selenium (µg/L)	<1*	NA	NA
Arsenic (µg/L)	<1*	NA	NA
Mercury (µg/L)	<0.05*	NA	NA

All units are mg/L unless otherwise specified.

¹ - mini-piezometer SP-P30, SP-P46, SP-P47, SP-P48, SP-P49, SP-P50, SP-P51 and SP-P52² - monitoring well B5³ - monitoring well D1-1

* only one sample analysed

NA - not analysed

TABLE 4.10: ESTIMATED MASS FLUXES AT SEEPAGE SITES A AND 1

Parameter	Average Concentration (mg/L)	Volumetric Water Flux ¹ (m ³ /yr)	Mass Flux	
			(kg/yr)	(g/y.m ²)
Site A		5.2x10 ³		
Chloride	89		4.6x10 ²	4.6
Sulphate	468		2.4x10 ³	2.4x10 ¹
Phenols	0.015		7.8x10 ⁻²	7.8x10 ⁻⁴
PAHs	0.004		2.1x10 ⁻²	2.1x10 ⁻⁴
Site 1		2.5x10 ³		
Chloride	286		7.1x10 ²	7.1x10 ⁻¹
Sulphate	186		4.6x10 ²	4.6x10 ⁻¹
Phenols	<0.001		-	-
PAHs ¹	<0.003		-	-

¹ - Volumetric fluxes are given in Table 4.4.

TABLE 4.11: COMPARISON OF MASS FLUX AT SEEPAGE SITES AND THROUGH GROUNDWATER

Parameter	Mass Flux (kg/yr)	
	Seepage Sites A and 1	Groundwater
Chloride	1.2×10^3	2.2×10^4
Sulphate	2.9×10^3	7.9×10^4
Phenols	7.8×10^{-2}	2.5
PAHs	2.1×10^{-2}	2.9×10^3

TABLE 5.1: HYDROLOGICAL INSTRUMENTATION BY STATION EMPLOYED AT THE ALGOMA SLAG SITE

STATION	Location	INSTRUMENTATION				
		Staff Gauge	Continuous Water Level Recorder*	Control Structure	Stilling Well	Rain Gauge
SW1	West Davignon Diversion at St. Marys River	X	X	rectangular weir	X	
SW2	West Davignon Diversion at Baseline Road	X				
SW3	Bennett Creek Upstream of Baseline Road Ditch	X				
SW4	Spring Creek at Bennett Creek	X		18" culvert		
SW5	Baseline Road Ditch at Snow Dump Road	X	X	dual 18" culverts	X	X

* warm weather installment only (operational periods August 1988 to December 1988 and May 1989 to July 1989).

TABLE 5.2: COMPARISON OF OBSERVED AND PREDICTED FLOWS FOR
THE SW1 FLOW MONITORING STATION

Head (m)	Predicted Flow (L/s)	Observed Flow (L/s)
0.0254	1.33	1.33
0.1078	47.0	47.1
0.1524	80.6	NM
0.1854	147	152

TABLE 5.3:

COMPARISON OF AVERAGE MONTHLY AIR TEMPERATURES
DURING THE MONITORING PERIOD (AUGUST 1988 TO JULY
1989) WITH THE LONG TERM NORMALS

Month	<u>Sault Ste. Marie Airport</u>		<u>Sault Ste. Marie Station #2</u>	
	1988-89 (°C)	Long Term Normal (°C)	1988-89 (°C)	Long Term Normal (°C)
August	18.2	16.9	19.2	17.5
September	13.1	12.8	13.5	13.1
October	5.2	7.6	4.9	7.6
November	2.7	0.7	2.4	0.6
December	-7.1	-6.7	-7.3	-6.9
January	-7.1	-10.1	-6.6	-10.2
February	-12.3	-10.0	-11.6	-9.0
March	-7.6	-5.1	-6.3	-4.2
April	2.5	3.1	2.7	3.6
May	10.5	9.1	12.4	10.3
June	14.4	14.6	15.2	14.9
July	19.2	17.3	20.3	17.8
Average for Period	4.3	4.2	4.9	4.6

TABLE 5.4:

COMPARISON OF PRECIPITATION MEASUREMENTS AT THE
ALGOMA SLAG SITE WITH OBSERVATIONS FROM THE AES
STATIONS DURING THE SURFACE WATER MONITORING
PERIOD

Period	Algoma Slag Site	Sault Ste. Marie	
	SW-5 Rain Gauge	Airport	Station #2
	(mm)	(mm)	(mm)
Aug. 11 - Sept. 24, 1988	152.2	169.4	191.4
Sept. 24 - Oct. 5	44.5	59.2	51.1
Oct. 5 - Oct. 22	35.4	36.0	47.6
Oct. 22 - Nov. 7	105.0	137.6	131.0
Nov. 7 - Nov. 20	43.2	52.1	40.5
Nov. 20 - Dec. 2	43.0	43.8	48.6
June 16 - July 5, 1989	12.0	14.0	21.8
Total	435.3	512.1	532.0

TABLE 5.5: MONTHLY PRECIPITATION AMOUNTS FOR 1988-89 WITH THE LONG-TERM NORMALS (number of days with precipitation noted in brackets)

Month		<u>Sault Ste. Marie Airport</u>		<u>Sault Ste. Marie Station #2</u>	
		1988-89 (mm)	Normal (mm)	1988-89 (mm)	Normal (mm)
1988	August	137.8 (15)	82.7 (11)	147.5 (20)	95.0 (11)
	September	76.8 (13)	95.3 (13)	97.3 (16)	108.4 (14)
	October	139.4 (19)	74.2 (15)	130.4 (20)	85.0 (14)
	November	169.7 (24)	85.7 (17)	160.1 (27)	92.5 (18)
	December	82.7 (24)	79.6 (20)	163.2 (26)	92.0 (19)
1989	January	63.2 (23)	74.0 (20)	95.4 (25)	87.0 (20)
	February	58.9 (17)	68.0 (15)	58.4 (24)	54.6 (17)
	March	59.6 (16)	60.4 (13)	78.8 (22)	62.6 (13)
	April	51.8 (14)	64.4 (11)	54.8 (16)	60.4 (11)
	May	54.2 (10)	84.2 ((12)	53.9 (13)	76.1 (11)
	June	59.0 (12)	74.3 (11)	66.2 (14)	88.4 (12)
	July	8.4 (9)	55.6 (9)	10.9 (8)	70.8 (10)
Total for Period		902.5 (196)	898.4 (167)	1,115.9 (233)	972.8 (170)

TABLE 5.6: SURFACE INFILTRATION MEASUREMENTS AT THE ALGOMA SLAG SITE

Site No.	Description	Infiltration Rate Range (cm/s)
1	Storage Area (coarse to fine slag)	1.8×10^{-2} - 2.2×10^{-1}
2	Sand Disposal Area (sand over slag)	1.3×10^{-1} - 1.5×10^{-1}
3	Slag Site 1 (very coarse slag; small plants, lateral roots)	1.5×10^{-1} - 1.8×10^{-1}
4	Aspen Tree Site (very coarse slag)	3.0×10^{-1} - 3.2×10^{-1}
5	Slat Site 2 (medium to coarse slag)	8.2×10^{-2} - 1.0×10^{-1}
6	Wood Pile Site (near St. Marys River and West Davignon)	3.1×10^{-2} - 3.9×10^{-2}
7	Filter Cake Disposal Site (medium to fine material over slag)	3.4×10^{-2} - 3.9×10^{-2}
8	Slat Site 3 (very small poplar trees 1-2'; medium to coarse slag)	1.7×10^{-2} - 2.1×10^{-2}
9	Roadway (oil sprayed with cracks)	1.4×10^{-2} - 1.9×10^{-2}
10	Cable Compound (vegetated site)	1.7×10^{-2} - 1.8×10^{-2}
11	Domtar Site (beside coke pile)	1.7×10^{-2} - 2.1×10^{-2}

TABLE 5.7: SUMMARY OF FIELD MEASUREMENTS COLLECTED DURING SURFACE WATER SAMPLING

	Aug. 13/88				Sept. 24/88			Oct. 22/88			Dec. 2/88			April 11/89				May 12/89				June 16/89			
	T ¹	pH	DO ²	Cond. ³	T	pH	Cond.	T	pH	Cond.	T	pH	Cond.	T	pH	DO	Cond.	T	pH	DO	Cond.	T	pH	DO	Cond.
SW1	23.5	7.2	8.0	321	16.0	7.5	101	7.0	7.8	95	1.0	7.5	87	-1.0	6.5	16.4*	80	11.0	6.5	12.2*	120	15.5	7.7	9.4	140
SW2	21.5	7.7	8.4	171	15.0	8.0	67	7.0	7.9	71	1.5	7.9	45	-1.0	7.2	14.8	55	9.0	6.8	11.0	65	15.5	7.9	-	-
SW3	18.0	6.8	8.1	337	12.5	8.2	140	7.0	8.4	91	3.0	8.3	80	1.5	8.1	12.6	82	9.0	10.0	13.2	80	-	-	-	-
SW4	23.0	7.7	6.4	4220	18.5	7.8	3200	8.5	7.5	2620	1.5	8.6	1760	4.5	9.4	7.9	2400	12.5	6.6	8.8	2000	16.0	8.2	8.8	3490
SW5	18.0	11.3	6.1	5280	17.5	11.3	5930	9.0	11.4	6060	60	11.0	3350	6.0	12.1	6.5	3100	10.5	12.5	8.6	4200	18.0	11.3	5.2	11200
SW6	22.5	8.9	4.5	6330	-	-	-	-	-	-	4.5	8.9	1912	5.0	11.4	4.1	2100	-	-	-	-	-	-	-	-
SW7	17.0	7.7	-	145	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SW8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15.0	8.9	9.2	480
SW9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15.0	9.1	9.6	490

- 1 Temperature (°C)
 2 (mg/L)
 3 Specific Conductance (µS/cm)
 * dissolved oxygen saturation
 - not measured

TABLE 5.8: SURFACE WATER LOADING ESTIMATES FOR STATION SW1 THROUGH SW5

Parameter	Station				
	West Davignon Downstream (SW1)	West Davignon Upstream (SW2)	Bennett Creek (SW3)	Spring Creek (SW4)	Baseline Road Ditch (SW5)
Chloride	613	461	373	105	695
Fluoride	4.1	3.5	1.7	0.086	0.329**
Sulphate	1,660	533	326	19.2	192
Nitrate-N	11.7	10.5	10.3	0.0083*	0.078**
TKN	28.6	16.9	7.1	0.196	1.25
Total Phosphorus (g/d)	508	578	368	2.30	2.64
Phenol (g/d)	ND	ND	47.3	28.4	10.8
PAH (g/d)	2.34	2.04	13.1 ⁺	40.8	54
Metals					
Zinc	ND	0.818	0.921	0.112	0.0068
Manganese	7.59	3.04	2.03	0.113	0.0814
Copper	ND	ND	ND	ND	0.0032
Iron	103	30.4	19.2	ND	0.285
Chromium (g/d)	ND	ND	ND	3.28	22.0
Nickel (g/d)	ND	ND	ND	1.51	10.5
Calcium	1,090	602	342.0	47.0	393
Aluminum	12.3	17.5	12.4	0.045*	0.244
Magnesium	228.0	143.0	84.4	1.23	1.40
Barium	0.876	0.993	0.526*	0.0133*	0.0542
Potassium	150	54.3	38.9	3.24	36.30
Strontium	4.85	2.98	1.45*	0.177*	1.13
Sodium	371	283	145	7.44	18.30

All loads are in kilograms per day (kg/d) unless otherwise noted.

* weighted average.

** regression estimate used.

+ value based on one sample only.

ND not determined.

TABLE 5.9: SURFACE WATER LOADING ESTIMATES TO ST. MARYS RIVER FROM ON-SITE SOURCES

Parameter	West Davignon Diversion			Bennett Creek		
	Upstream (SW2)	Downstream (SW1)	Net Discharge to St. Marys River From On- Site Sources	Upstream (SW3* SW7)	Downstream	Net Discharge to St. Marys River From On- Site Sources
Chloride	461	613	152	373	1,173	800
Fluoride	3.5	4.09	0.6	1.7	2.12	0.42
Sulphate	533	1,660	1,127	326	537	211
Nitrate-N	10.5	11.7	1.2	10.3	10.4	0.086
TKN	16.9	28.6	11.7	7.1	8.55	1.45
Total Phosphorus (g/d)	578	508	ND	368	373	5
Phenol (g/d)	ND	ND	ND	47.3	86.5	39.2
PAH (g/d)	2.04	2.34	0.3	13.1	108.1	95.0
Metals						
Zinc	0.818	ND	ND	0.921	1.04	0.119
Manganese	3.04	7.59	4.55	2.03	2.22	0.194
Copper	ND	ND	ND	ND	0.003	0.003
Iron	30.4	103	726	19.2	19.5	0.285
Chromium (g/d)	ND	ND	ND	ND	252	252
Nickel (g/d)	ND	ND	ND	ND	12.0	12.0
Calcium	602	1,090	488	342.0	782	440
Aluminum	17.5	12.3	ND	12.4	12.7	0.289
Magnesium	143	228	85	84.4	87.0	2.6
Barium	12.8	0.876	ND	0.526	1.20	0.675
Potassium	54.3	150	95.2	38.9	78.4	39.5
Strontium	2.98	4.85	1.87	1.45	2.76	1.31
Sodium	283	371	88	145	170.7	25.7

All loads are in kilograms per day (kg/d) unless otherwise noted.
ND - not determined.

TABLE 6.1: COMPARISON OF GROUNDWATER AND SURFACE WATER DISCHARGE RATES

Surface Drainage Feature	Site Discharge (m ³ /yr)	
	Surface Water	Groundwater
Baseline Road Ditch	1.2x10 ⁵	1.7x10 ⁵
Bennett Creek	0 (9.6x10 ⁶)*	3.8x10 ⁴
Spring Creek	3.2x10 ⁴	3.6x10 ⁴
West Davignon Diversion	0 (2.1x10 ⁷)*	<u>2.6x10²</u>
Total Creek Flow to St. Marys River	3.1x10 ⁴	2.5x10 ⁵
Direct Discharge of Groundwater to St. Marys River	-	2.2x10 ⁵

* No measurable flow difference between upstream and downstream stations. Total flow reported in parentheses.

TABLE 6.2: COMPARISON OF GROUNDWATER AND SURFACE WATER MASS FLUXES (kg/day)

Surface Water Body	Direct Discharge To St. Marys River	Baseline Road Ditch		Bennett Creek		Spring Creek		West Davignon Diversion	
Parameter	GW Flux	GW Flux	SW Flux	GW Flux	SW*** Flux	GW Flux	SW Flux	GW Flux	SW Flux
Chloride	6.0×10^1	7.0×10^0	7.0×10^2	9.1×10^{-1}	8.0×10^2	1.4×10^0	1.1×10^2	9.3×10^{-2}	1.5×10^2
Fluoride	4.6×10^{-1}	1.3×10^{-1}	$3.3 \times 10^{-1}\#$	2.3×10^{-2}	4.2×10^{-1}	1.1×10^{-2}	8.6×10^{-2}	1.2×10^{-3}	6.0×10^{-1}
Sulphate	2.1×10^2	2.0×10^1	1.9×10^2	1.2×10^0	2.1×10^2	2.9×10^0	1.9×10^1	7.7×10^{-1}	1.1×10^3
Nitrate-N	2.1×10^{-2}	1.4×10^{-2}	$7.8 \times 10^{-2}\#$	2.5×10^{-3}	8.6×10^{-2}	1.2×10^{-1}	$8.3 \times 10^{-3}\ast$	2.2×10^{-5}	1.2×10^0
TKN	2.3×10^0	1.9×10^0	1.3×10^0	4.7×10^{-2}	1.4×10^0	1.8×10^{-1}	2.0×10^{-1}	6.3×10^{-3}	1.2×10^1
Total Phosphorous	9.9×10^{-2}	1.1×10^{-2}	2.6×10^{-3}	3.4×10^{-3}	4.9×10^{-3}	4.9×10^{-3}	2.3×10^{-3}	2.5×10^{-4}	ND
Phenols	6.8×10^{-3}	1.4×10^{-2}	1.1×10^{-2}	1.8×10^{-4}	3.9×10^{-2}	6.6×10^{-3}	2.8×10^{-2}	3.0×10^{-6}	ND
PAH	7.7×10^{-3}	1.3×10^{-3}	5.4×10^{-2}	1.6×10^{-4}	9.5×10^{-2}	5.2×10^{-1}	4.1×10^{-2}	9.7×10^{-7}	3.0×10^{-4}
Zinc	4.9×10^{-3}	2.7×10^{-3}	6.8×10^{-3}	3.5×10^{-4}	8.0×10^{-3}	ND	1.3×10^{-3}	1.8×10^{-5}	ND
Manganese	8.8×10^{-2}	1.7×10^{-1}	8.1×10^{-2}	9.2×10^{-3}	1.9×10^{-1}	1.8×10^{-2}	1.1×10^{-1}	1.5×10^{-3}	4.6×10^0
Copper	1.3×10^{-3}	1.6×10^{-3}	3.2×10^{-3}	6.5×10^{-4}	3.0×10^{-3}	ND	ND	4.5×10^{-6}	ND
Iron	1.5×10^0	1.9×10^0	2.9×10^{-1}	8.7×10^{-3}	2.9×10^{-1}	7.6×10^{-2}	1.1×10^{-1}	2.3×10^{-2}	7.3×10^1
Chromium	8.1×10^{-3}	2.1×10^{-3}	2.2×10^{-2}	ND	2.5×10^{-2}	ND	3.3×10^{-3}	1.5×10^{-5}	ND
Nickel	3.0×10^{-3}	3.5×10^{-4}	1.1×10^{-2}	ND	1.2×10^{-2}	ND	1.5×10^{-3}	1.0×10^{-5}	ND

... continued

TABLE 6.2: COMPARISON OF GROUNDWATER AND SURFACE WATER MASS FLUXES (kg/day)

Surface Water Body	Direct Discharge To St. Marys River	Baseline Road Ditch		Bennett Creek		Spring Creek		West Davignon Diversion	
Parameter	GW Flux	GW Flux	SW Flux	GW Flux	SW*** Flux	GW Flux	SW Flux	GW Flux	SW Flux
Calcium	1.6x10 ²	2.2x10 ¹	3.9x10 ²	4.7x10 ⁰	4.4x10 ²	3.7x10 ⁰	4.7x10 ¹	2.6x10 ⁻¹	4.9x10 ²
Aluminum	2.4x10 ⁻¹	8.0x10 ⁻²	2.4x10 ⁻¹	2.1x10 ⁻²	2.9x10 ⁻¹	1.4x10 ⁻²	4.5x10 ^{-2*}	2.8x10 ⁻⁴	ND
Magnesium	2.4x10 ⁰	2.7x10 ⁰	1.4x10 ⁰	7.4x10 ⁻¹	2.6x10 ⁰	1.8x10 ⁻¹	1.2x10 ⁰	6.6x10 ⁻²	8.5x10 ¹
Barium	1.1x10 ⁻¹	1.0x10 ^{-2**}	5.4x10 ⁻²	3.5x10 ^{-3**}	6.8x10 ⁻¹	4.9x10 ⁻³	1.3x10 ^{-2*}	5.8x10 ⁻⁵	ND
Potassium	7.0x10 ¹	2.3x10 ⁰	3.6x10 ¹	1.9x10 ⁻¹	4.0x10 ¹	5.4x10 ⁻¹	3.2x10 ⁰	1.5x10 ⁻¹	9.5x10 ¹
Strontium	6.1x10 ⁻¹	1.1x10 ^{-1**}	1.1x10 ⁰	1.8x10 ^{-2**}	1.3x10 ⁰	7.9x10 ⁻³	1.8x10 ^{-1*}	9.5x10 ⁻⁴	1.9x10 ⁰
Sodium	3.4x10 ¹	1.3x10 ¹	1.8x10 ¹	1.3x10 ⁰	2.6x10 ¹	1.5x10 ⁰	7.4x10 ⁰	1.1x10 ⁻¹	8.8x10 ¹

GW groundwater

SW surfacewater

* weighted average

** may not be representative, parameter not analyzed for at all wells

regression estimate used

ND not determined - concentration(s) below detection limit

... continued

TABLE 6.3: TOTAL OFF-SITE MASS FLUX

	MASS FLUX (kg/day)					
Surface Water Body	St. Marys River ⁽¹⁾	Baseline Road Ditch ⁽²⁾	Bennett Creek ⁽¹⁾	Spring Creek ⁽²⁾	West Davignon Diversion ⁽¹⁾	Total Off-Site Flux
<u>Parameter</u>						
Chloride	6.0x10 ¹	7.0x10 ²	9.1x10 ⁻¹	1.1x10 ²	9.3x10 ⁻²	8.7x10 ²
Fluoride	4.6x10 ⁻¹	3.3x10 ⁻¹	2.3x10 ⁻²	8.6x10 ⁻²	1.2x10 ⁻³	9.0x10 ⁻¹
Sulphate	2.1x10 ²	1.9x10 ²	1.2x10 ⁰	1.9x10 ¹	7.7x10 ⁻¹	4.2x10 ²
Total Cyanide	1.2x10 ⁻¹	8.0x10 ⁻⁴⁽¹⁾	ND	9.9x10 ⁻⁵⁽¹⁾	8.2x10 ⁻⁵	1.2x10 ⁻¹
Nitrate-N	2.1x10 ⁻²	7.8x10 ⁻²	2.5x10 ⁻³	8.3x10 ⁻³	2.2x10 ⁻⁵	1.1x10 ⁻¹
TKN	2.3x10 ⁰	1.3x10 ⁰	4.7x10 ⁻²	2.0x10 ⁻¹	6.3x10 ⁻³	3.9x10 ⁰
Total Phosphorus	9.9x10 ⁻²	2.6x10 ⁻³	3.4x10 ⁻³	2.3x10 ⁻³	2.5x10 ⁻⁴	1.1x10 ⁻¹
Phenols	6.8x10 ⁻³	1.1x10 ⁻²	1.8x10 ⁻⁴	2.8x10 ⁻²	3.0x10 ⁻⁶	4.6x10 ⁻²
BTX	1.3x10 ⁻²	ND*(1)	3.3x10 ⁻³	4.3x10 ⁻¹⁽¹⁾	3.5x10 ⁻⁵	4.5x10 ⁻¹
PAH	7.7x10 ⁻³	5.4x10 ⁻²	1.6x10 ⁻⁴	5.2x10 ⁻¹	9.7x10 ⁻⁷	5.8x10 ⁻¹
<u>Metals</u>						
Zinc	4.9x10 ⁻³	6.8x10 ⁻³	3.5x10 ⁻⁴	1.3x10 ⁻³	1.8x10 ⁻⁵	1.3x10 ⁻²
Cadmium	3.9x10 ⁻⁴	2.1x10 ⁻⁴⁽¹⁾	1.4x10 ⁻⁵	5.9x10 ⁻⁵⁽¹⁾	1.9x10 ⁻⁷	6.7x10 ⁻⁴
Manganese	8.8x10 ⁻²	8.1x10 ⁻²	9.2x10 ⁻³	1.1x10 ⁻¹	1.5x10 ⁻³	2.9x10 ⁻¹
Cobalt	6.0x10 ⁻³	8.9x10 ⁻⁴⁽¹⁾	ND	ND ⁽¹⁾	8.9x10 ⁻⁶	6.9x10 ⁻³
Copper	1.3x10 ⁻³	3.2x10 ⁻³	6.5x10 ⁻⁴	ND ⁽¹⁾	4.5x10 ⁻⁶	5.2x10 ⁻³
Iron	1.5x10 ⁰	2.9x10 ⁻¹	8.7x10 ⁻³	7.6x10 ⁻²⁽¹⁾	2.3x10 ⁻²	1.9x10 ⁰
Chromium	8.1x10 ⁻³	2.2x10 ⁻²	ND	3.3x10 ⁻³	1.5x10 ⁻⁵	3.3x10 ⁻²
Nickel	3.0x10 ⁻³	1.1x10 ⁻²	ND	1.5x10 ⁻³	1.0x10 ⁻⁵	1.6x10 ⁻²

.... continued

TABLE 6.3: TOTAL OFF-SITE MASS FLUX

Surface Water Body	MASS FLUX (kg/day)					Total Off-Site Flux
	St. Marys River ⁽¹⁾	Baseline Road Ditch ⁽²⁾	Bennett Creek ⁽¹⁾	Spring Creek ⁽²⁾	West Davignon Diversion ⁽¹⁾	
<u>Parameter</u>						
Molybdenum	1.3x10 ⁻²	3.9x10 ⁻³ (1)	1.3x10 ⁻⁴	ND	1.9x10 ⁻⁵	1.7x10 ⁻²
Calcium	1.6x10 ²	3.9x10 ²	4.7x10 ⁰	4.7x10 ¹	2.6x10 ⁻¹	6.0x10 ²
Vanadium	2.0x10 ⁻²	2.4x10 ⁻³ (1)	7.8x10 ⁻⁴	ND ⁽¹⁾	2.8x10 ⁻⁵	2.3x10 ⁻²
Aluminum	2.4x10 ⁻¹	2.4x10 ⁻¹	2.1x10 ⁻²	4.5x10 ⁻²	2.8x10 ⁻⁴	5.5x10 ⁻¹
Magnesium	2.4x10 ⁰	1.4x10 ⁰	7.4x10 ⁻¹	1.2x10 ⁰	6.6x10 ⁻²	5.8x10 ⁰
Barium	1.1x10 ⁻¹	5.4x10 ⁻²	3.5x10 ^{-3**}	1.3x10 ⁻²	5.8x10 ⁻⁵	1.8x10 ⁻¹
Potassium	7.0x10 ¹	3.6x10 ¹	1.9x10 ⁻¹	3.2x10 ⁰	1.5x10 ⁻¹	1.1x10 ²
Strontium	6.1x10 ⁻¹	1.1x10 ⁰	1.8x10 ^{-2**}	1.8x10 ⁻¹	9.5x10 ⁻⁴	1.9x10 ⁰
Sodium	3.4x10 ¹	1.8x10 ¹	1.3x10 ⁰	7.4x10 ⁰	1.1x10 ⁻¹	6.1x10 ¹

ND not determined - concentration(s) below detection limits.

* may not be representative, parameter not analysed for at all wells.

(1) Based on groundwater estimates

(2) Based on surface water estimates

TABLE 6.4: SUMMARY OF TOTAL LOADING TO ST. MARYS RIVER

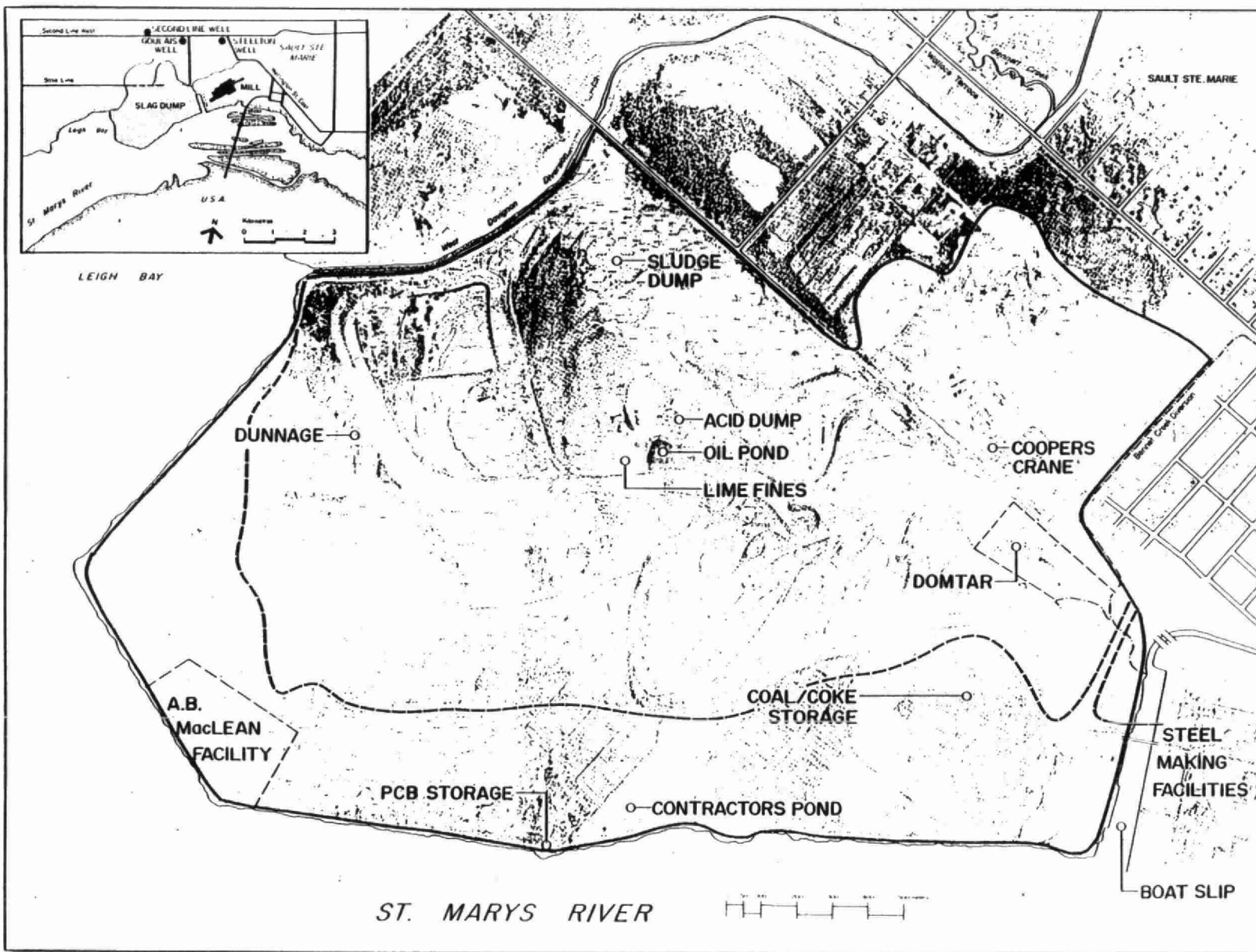
Parameter (kg/day) Source	Ammonia	Total Phosphorus	Chloride	Cyanide	Total Phenols	Copper	Iron	Lead	Mercury	Zinc	Total BTX	Total PAHs
DIRECT POINT-SOURCE DISCHARGES												
Municipal Sources												
Sault Ste. Marie, Ontario												
East End WPCP	2.0E+2	9.0E+1	2.0E+3	NA	5.1E-1	1.4E+0	4.3E+1	1.0E+0	5.0E-4	1.9E+0	4.3E-1	4.2E-1
West End WPCP	1.5E+1	5.7E+0	6.0E+2	NA	2.2E-2	2.0E-1	5.2E+0	1.9E-1	1.0E-4	3.6E-1	1.6E-2	4.0E-3
Sault Ste. Marie, Michigan												
POTW	NA	6.3E+0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Industrial Sources												
St. Marys Paper												
Sault Ste. Marie, Ontario	6.0E+0	4.7E+0	7.4E+2	NA	7.1E-1	3.3E-1	8.7E+0	1.7E-1	0.0E+0	9.0E-2	2.2E-1	5.1E-2
Algoma Steel Corp.												
Terminal Basin	6.0E+3	1.6E+1	1.1E+4	2.8E+1	8.2E+0	N	1.2E+3	2.6E+0	3.0E-3	3.2E+0	1.8E+0	1.6E-1
Bar and Strip Lagoon	2.9E+2	ND	6.7E+3	9.0E+1	8.0E-1	N	5.1E+2	2.9E+0	7.0E-3	2.9E+1	ND	2.4E-2
60" Blast Furnace Sewer	8.3E+0	4.5E+0	7.6E+2	9.6E+0	NA	1.4E-1	4.9E+1	6.8E-1	2.0E-3	2.1E+0	ND	0.0E+0
30" Blast Furnace Sewer	N	ND	5.0E+2	4.9E+0	NA	1.5E-1	1.3E+1	ND	N	3.3E-1	ND	7.0E-3
INDIRECT POINT-SOURCE DISCHARGES												
Industrial Sources												
Algoma Steel Corp.												
Integrated Steel Mill, East Davignon Creek												
Tube Mill Outfall	1.8E+1	2.7E+0	9.5E+2	2.9E-1	6.1E-1	NA	7.2E+1	NA	NA	7.6E-1	ND	4.0E-2
24" Cold Mill Basin OTCW	1.8E+1	2.7E+0	9.5E+2	2.9E-1	6.1E-1	NA	7.2E+1	NA	NA	7.6E-1	ND	4.0E-2
DIRECT NON POINT-SOURCE DISCHARGES												
Sault Ste. Marie, Ontario												
Stormwater Runoff	2.7E+1	1.1E+1	5.1E+3	7.4E-2	5.4E-1	1.6E+0	2.5E+2	4.3E+0	1.1E-3	1.0E+1	NA	4.9E-1
Algoma Slag Site Loading (kg/day)	NA	1.1E-1	8.7E+2	1.2E-1	4.6E-2	5.2E-3	1.9E+0	NA	NA	1.3E-2	4.5E-1	5.8E-1
Total Loading (kg/day)	6.5E+3	1.4E+2	3.0E+4	1.3E+2	1.2E+1	3.8E+0	2.2E+3	1.2E+1	1.4E-2	4.8E+1	2.9E+0	1.8E+0
Algoma Slag Site % Total Load	-	0%	3%	0%	0%	0%	0%	-	-	0%	15%	32%

Loading rates were obtained from Upper Great Lakes Connecting Channel Study, except for Algoma Slag Site.

ND - Not detected

NA - Not analyzed

N - Negative net loading



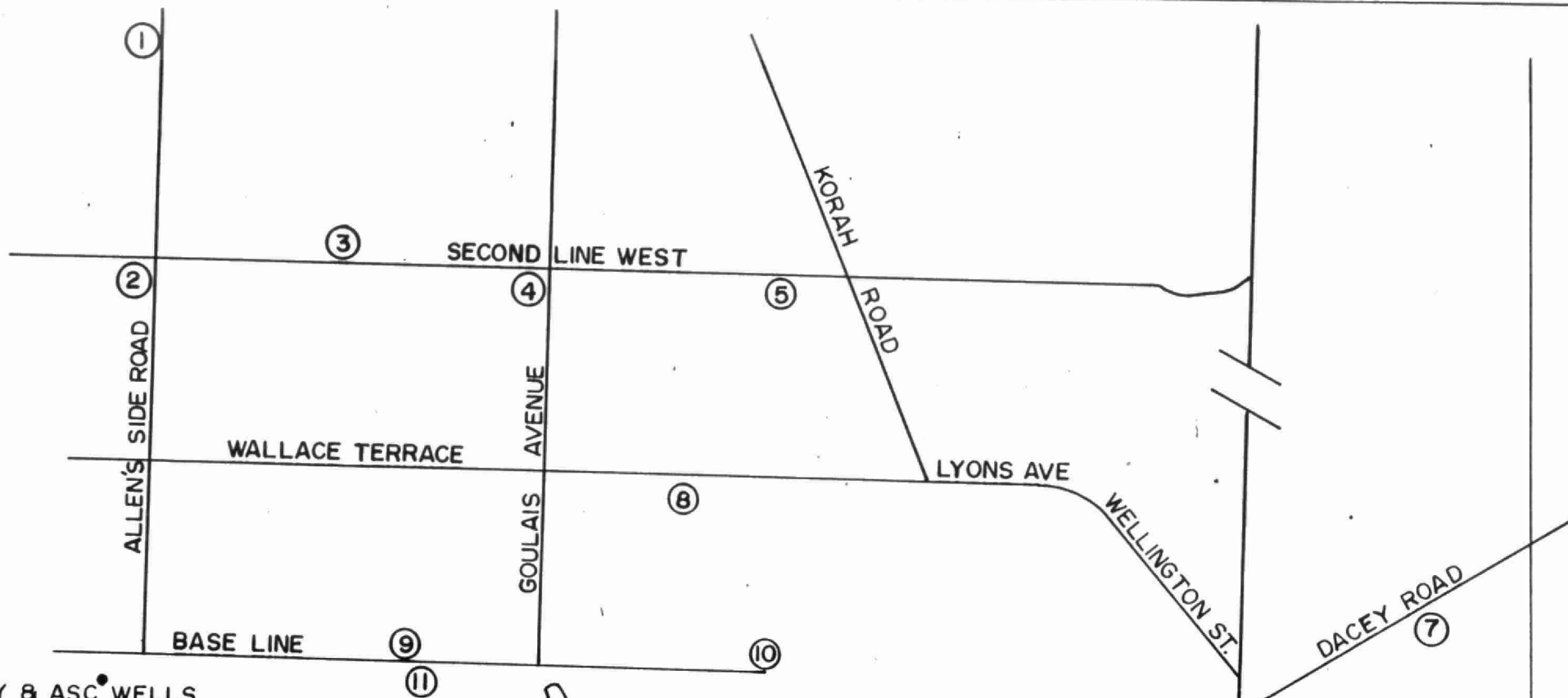
— approximate location of original shoreline

— slag disposal area

aerial photo dated 15 May 1984
by McElhanney Mapping Services

Locations of By-Products,
Algoma Slag Site

beak consultants limited	Figure 1.1	Dec 90 Rev. 00
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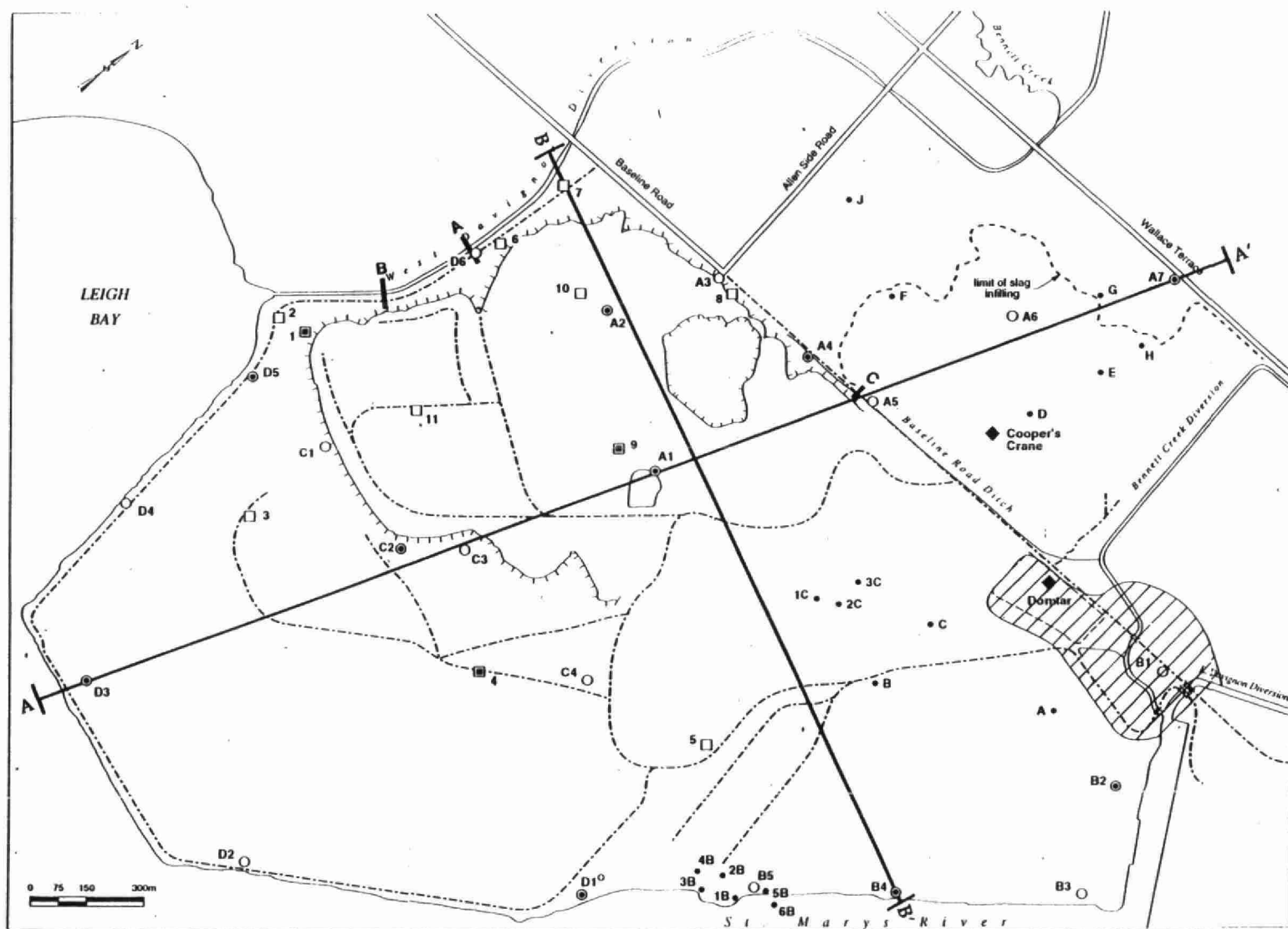
CITY & ASC WELLS

- (1) ALLEN'S SIDE ROAD NORTH
- (2) ALLEN'S SIDE ROAD AT SECOND LINE
- (3) 848 SECOND LINE
- (4) GOULAIS AVENUE
- (5) STEELTON
- (6) LORNA DRIVE
- (7) DACEY ROAD (SHANNON)
- (8) TUBE WELL
- (9) COPPERS WELL
- (10) No.2 BOF WELL
- (11) DOMTAR WELL

Sault Ste. Marie and Algoma Water Supply Wells

Sault Ste. Marie and Algoma Water Supply Wells		
ints	Figure 1.2	December 90 Rev. 00

(6)



- gravel road
- - - - - fence
- - - - - escarpment/depression
- A — A' cross section location
- area studied by Gartner Lee (1988), and Conestoga Rovers Assoc. (1988)

EXISTING INSTRUMENTATION

BEAK Wells (1988)

- monitoring well
- monitoring well nest

Geocon Wells (1983)

- monitoring well
- monitoring well nest

on-site water supply wells

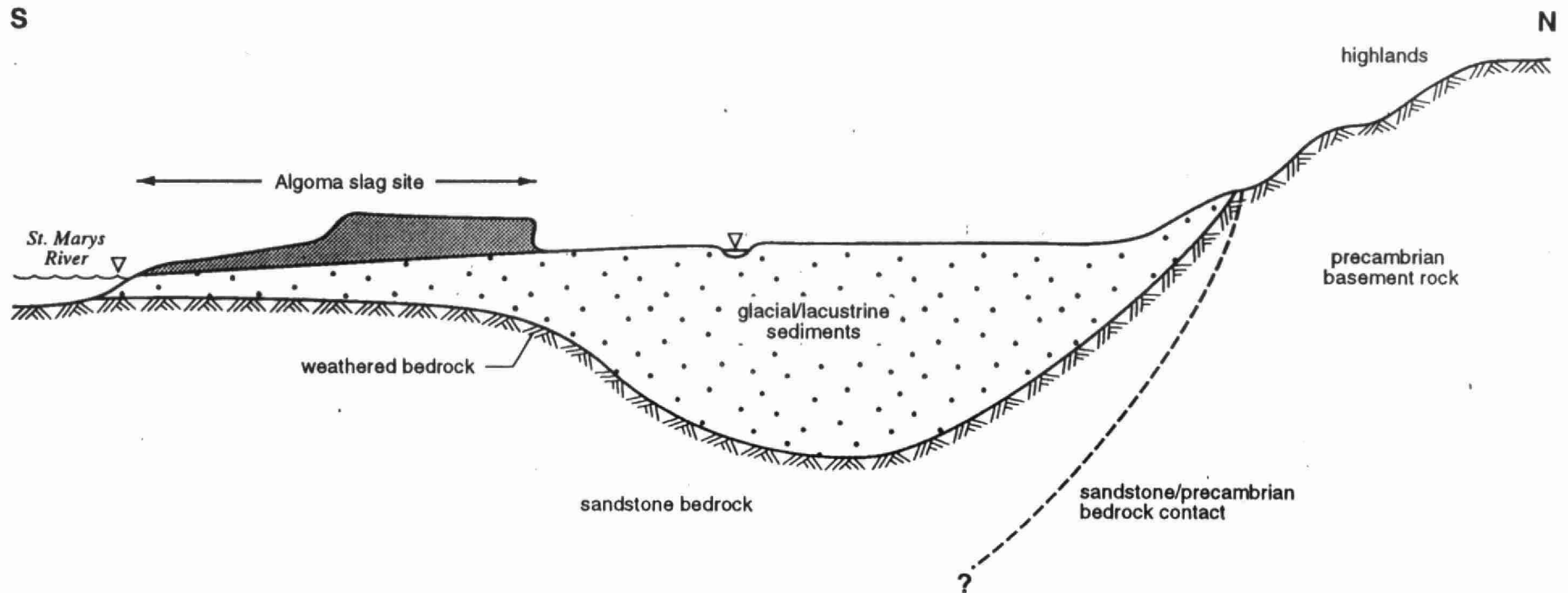
■ creek bed mini-piezometer transect location

FORMER BOREHOLES

- 1B Geocon (1980)
- 1C Geocon (1980)
- A Geocon (1964)

Locations of Existing and Former Boreholes and Wells, Algoma Slag Site

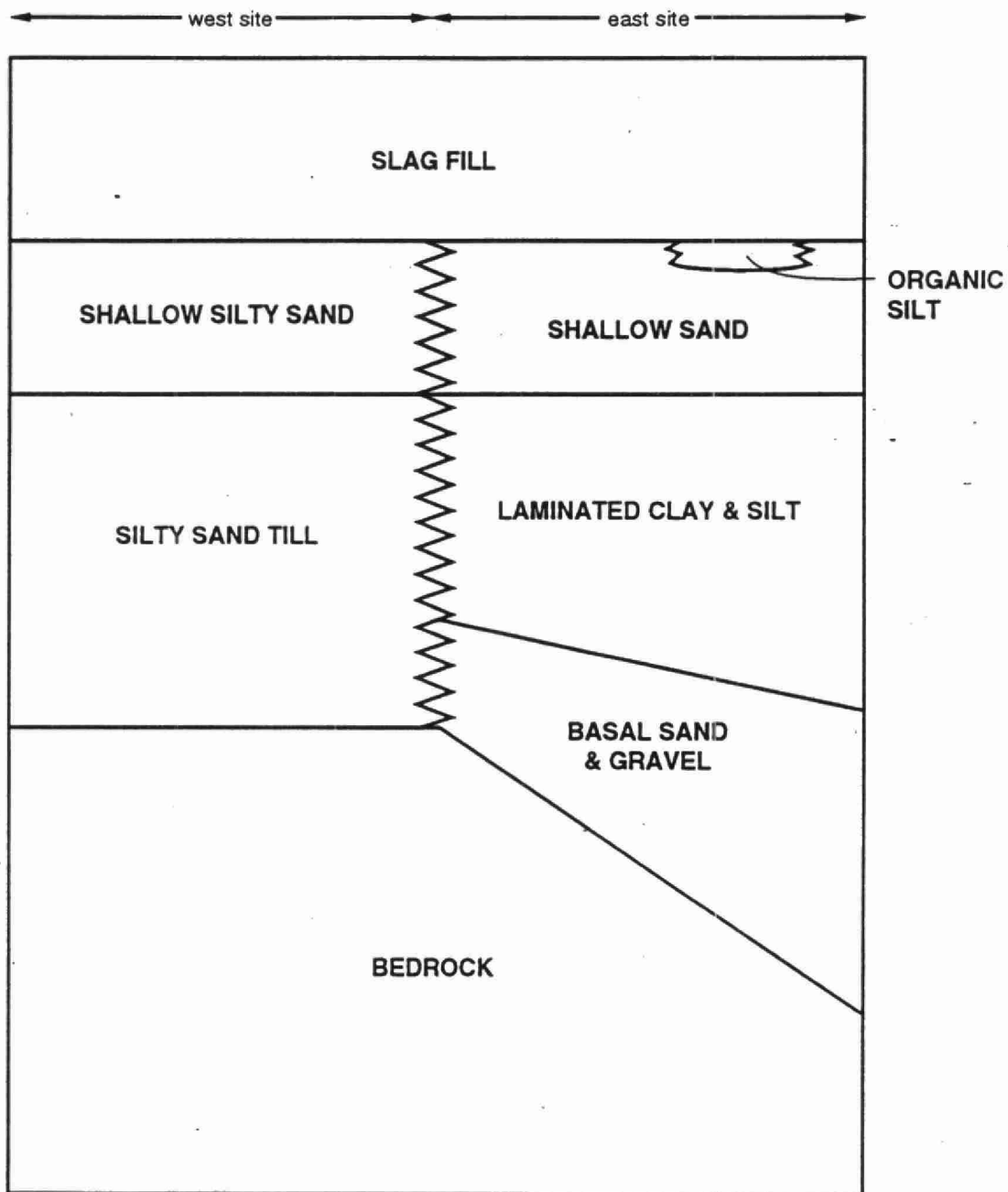
Figure 3.1	December 90 Rev. 00
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Schematic Regional Geologic Cross-Section

Figure
3.2

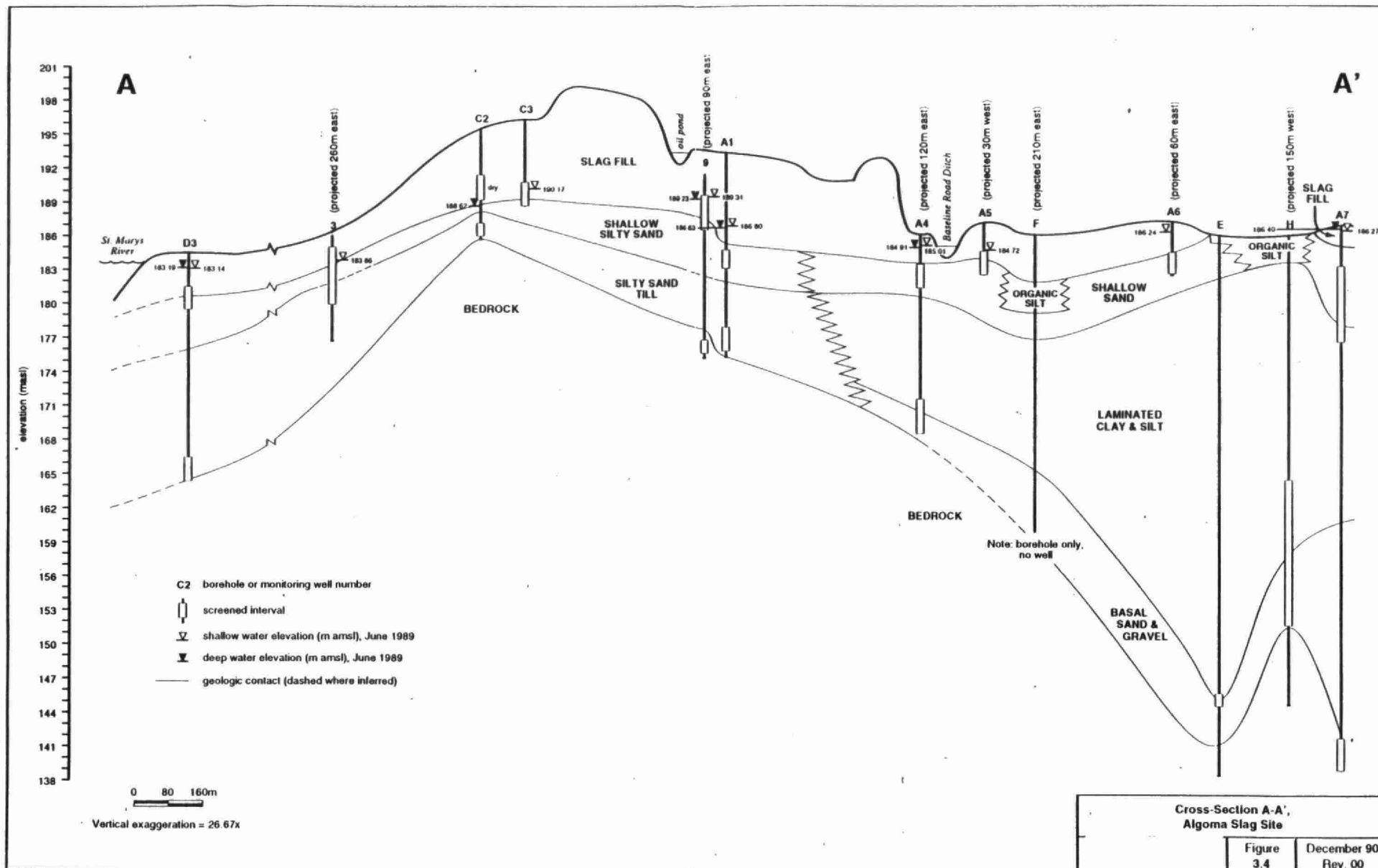
December 90
Rev. 00

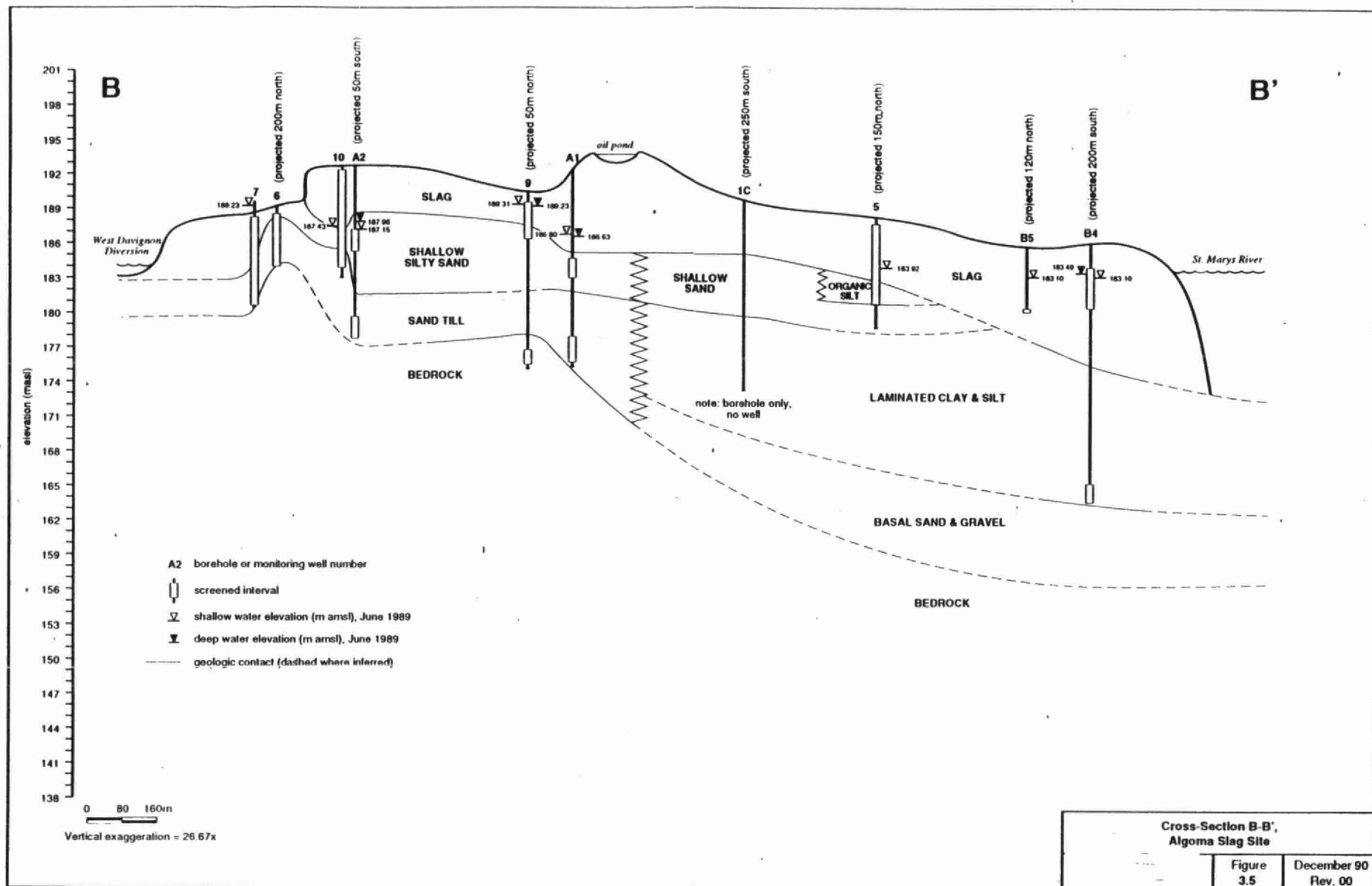


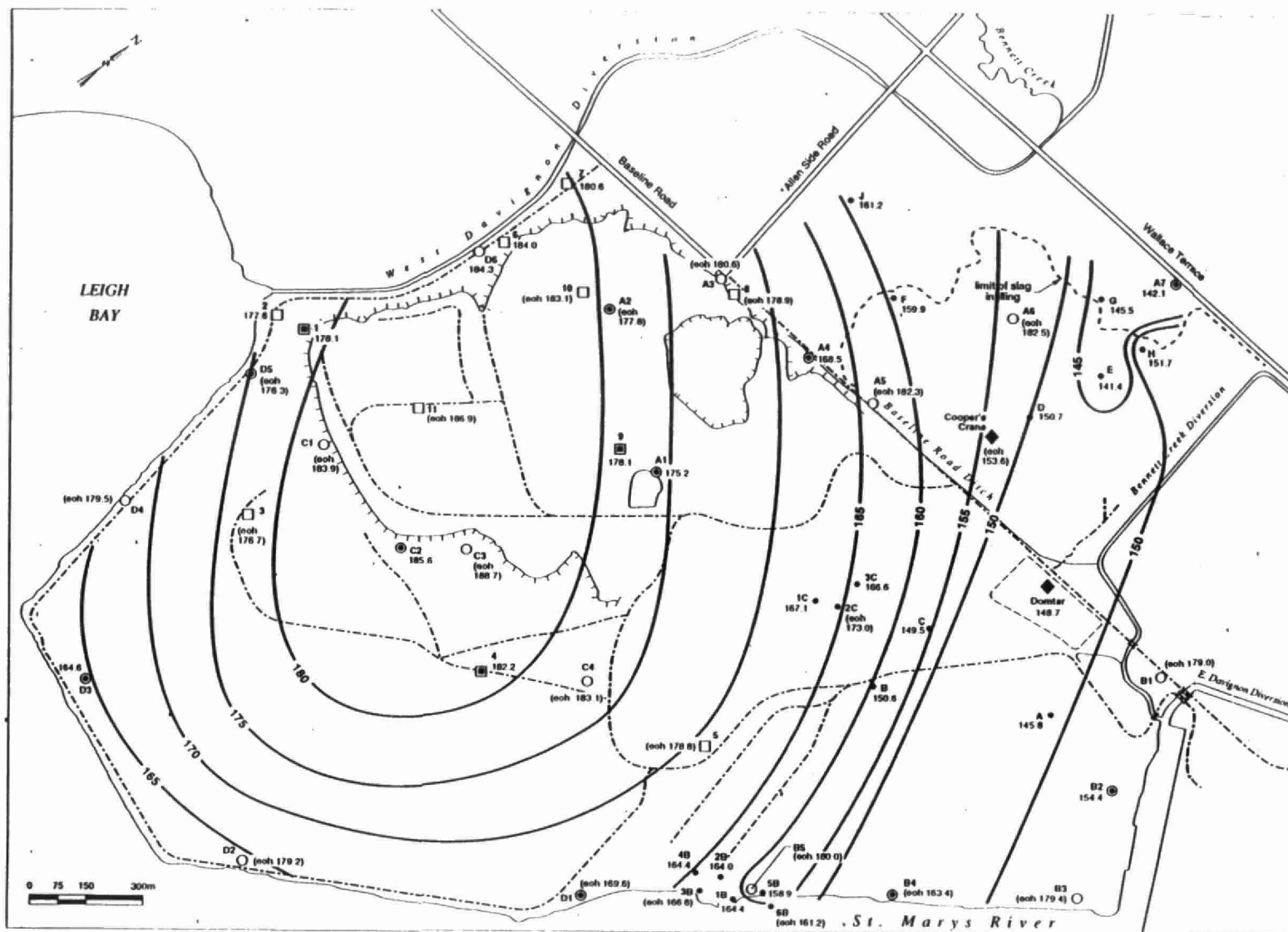
Algoma Slag Site Stratigraphic Column

Figure
3.3

December 90
Rev. 00







EXISTING INSTRUMENTATION

BEAK Wells (1988)

- monitoring well
- monitoring well nest

Geocon Wells (1983)

- monitoring well
- monitoring well nest

- ◆ on-site water supply wells

FORMER BOREHOLES

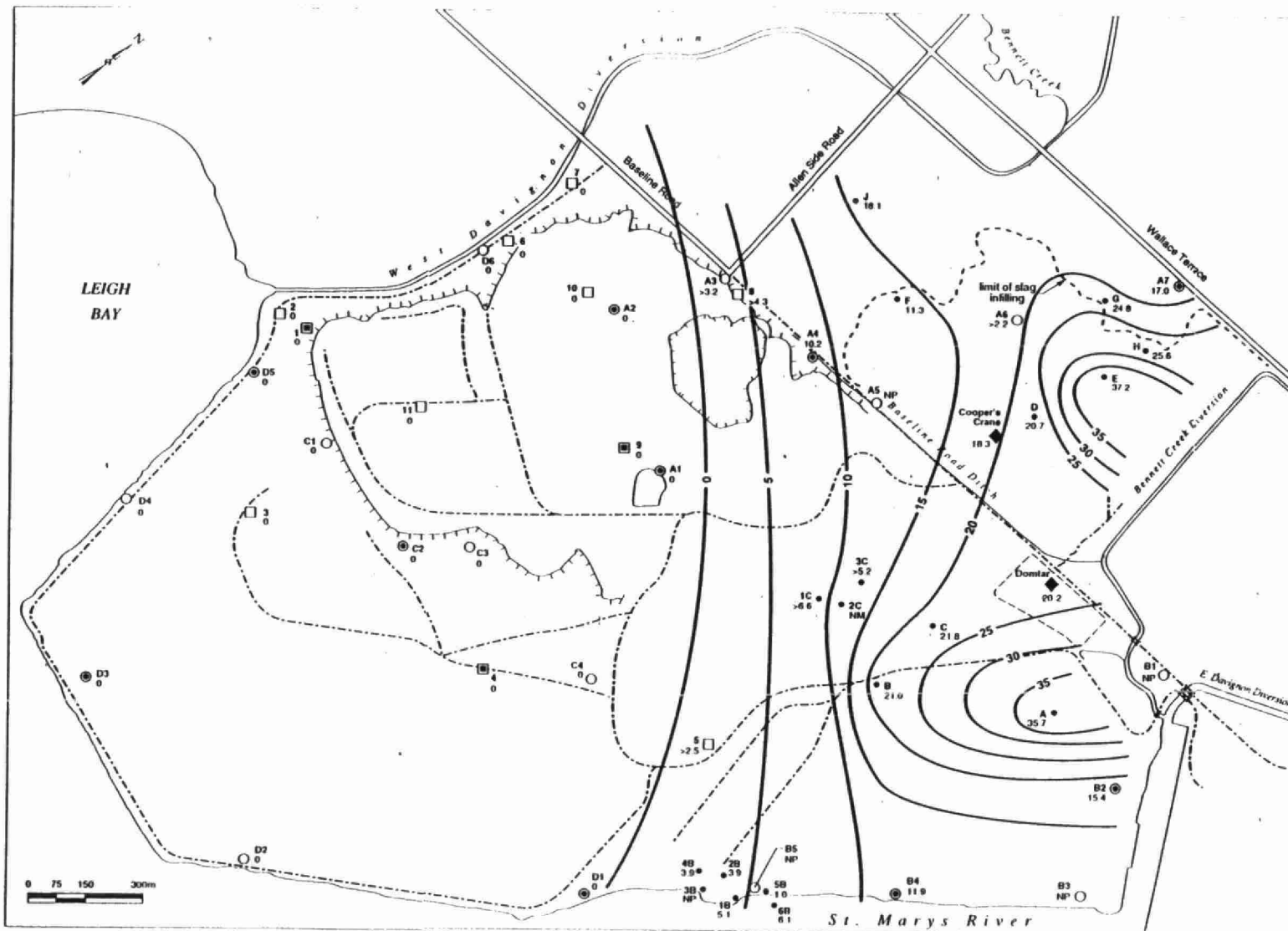
- 1B Geocon (1980)
- 1C Geocon (1980)
- A Geocon (1964)

DATA REPRESENTATION

- 154.4 elevation of bedrock surface (m amsl)
- (eoh 178.5) bedrock not encountered, elevation of end of borehole
- 150 bedrock surface topographic contour (m amsl)

Bedrock Topography Beneath the Algoma Slag Site

Figure	December 90
3.6	Rev. 00



EXISTING INSTRUMENTATION

BEAK Wells (1988)

- monitoring well
- ⊙ monitoring well nest

Geocon Wells (1983)

- monitoring well
- ⊠ monitoring well nest

- ◆ on-site water supply wells

FORMER BOREHOLES

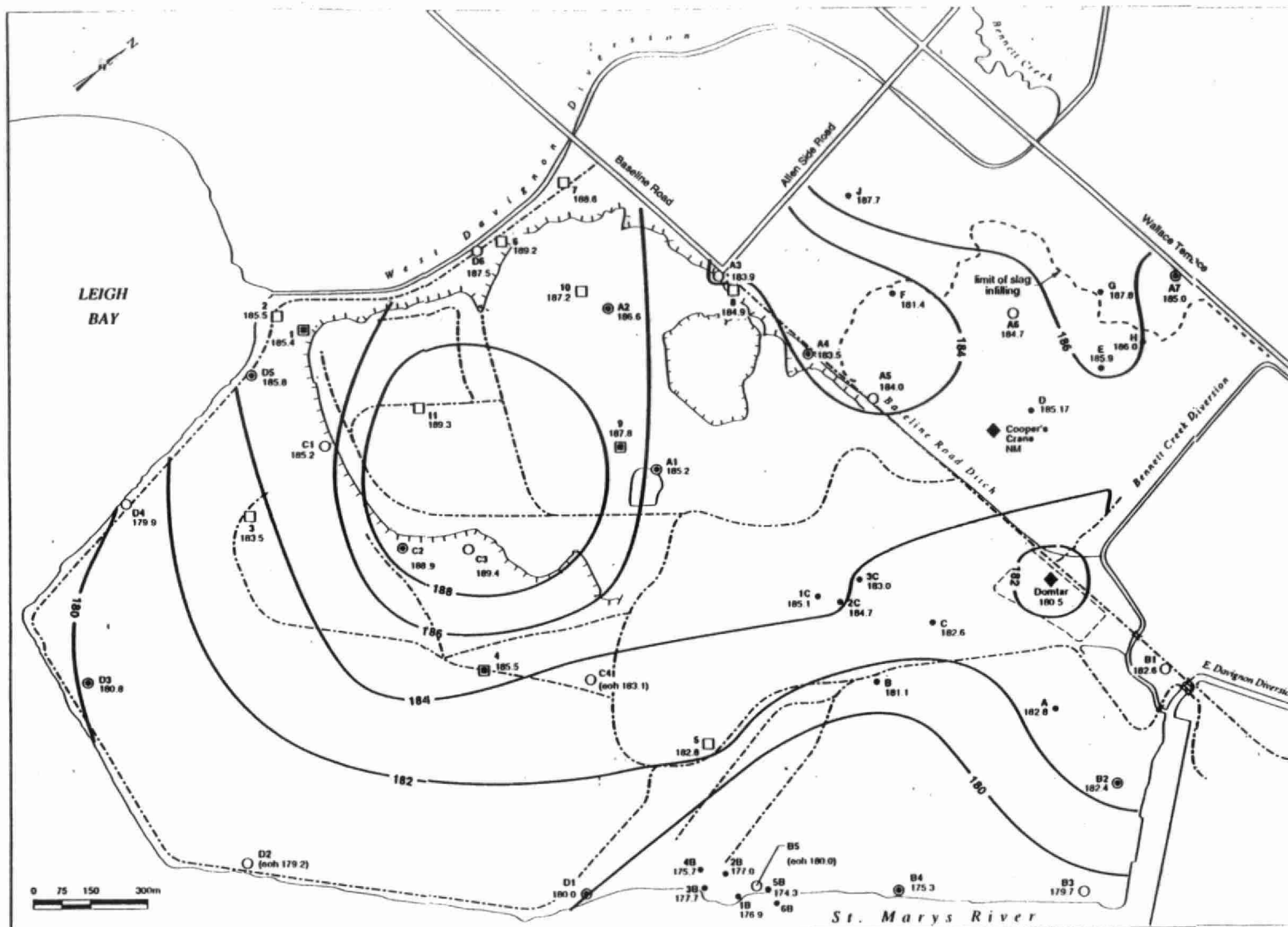
- 1B Geocon (1980)
- 1C Geocon (1980)
- A Geocon (1964)

DATA REPRESENTATION

- 20.2 thickness of laminated clay and silt (m)
- NP not penetrated
- NM not measured
- 20 laminated clay and silt isopach contour

Laminated Clay and Silt Thickness, Algoma Slag Site

Figure 3.7	December 90 Rev. 00
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- gravel road
- fence
- escarpment/depression

EXISTING INSTRUMENTATION

BEAK Wells (1988)

- monitoring well
- monitoring well nest

Geocon Wells (1983)

- monitoring well
- monitoring well nest

- ◆ on-site water supply wells

FORMER BOREHOLES

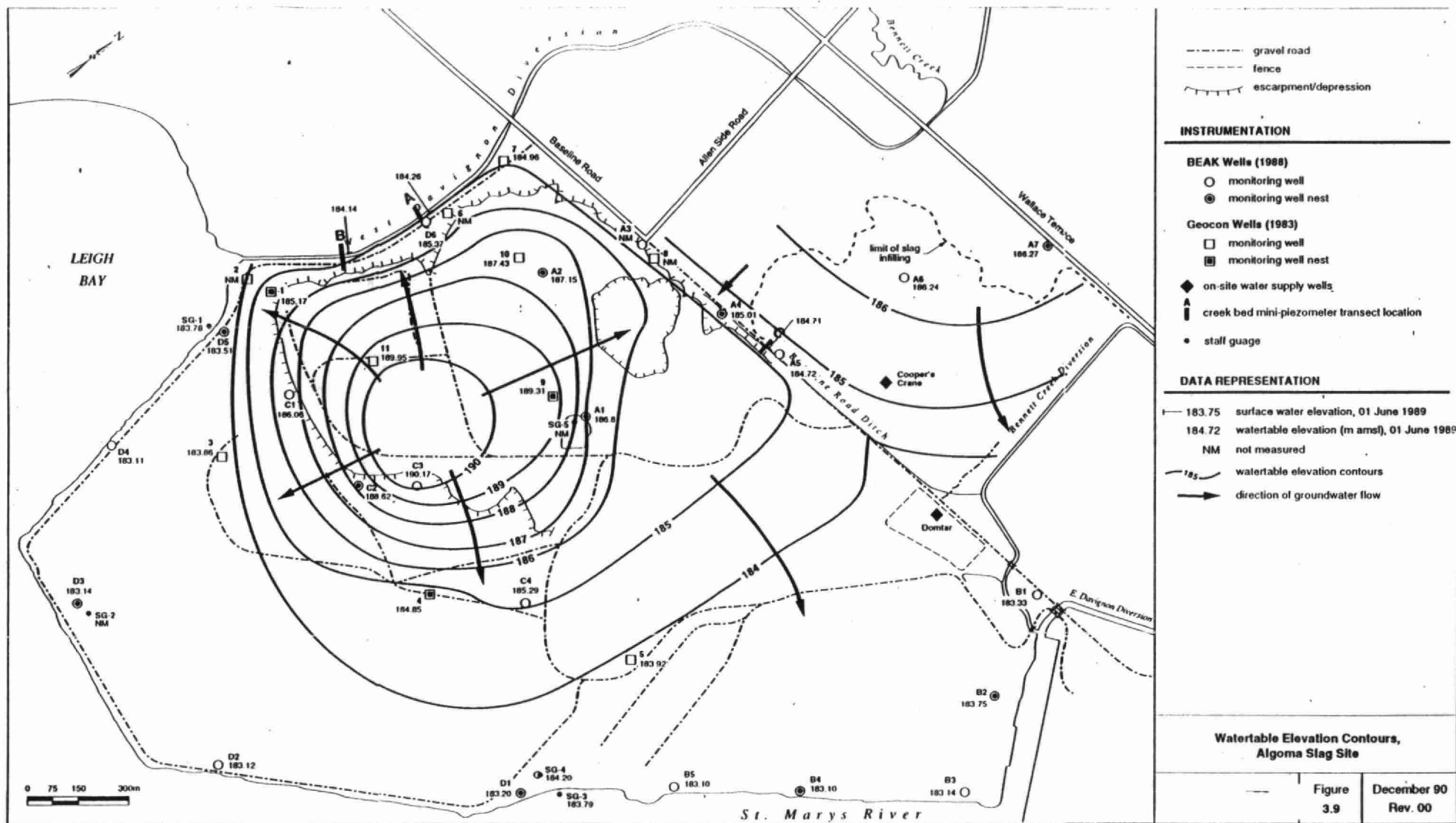
- 1B Geocon (1980)
- 1C Geocon (1980)
- A Geocon (1964)

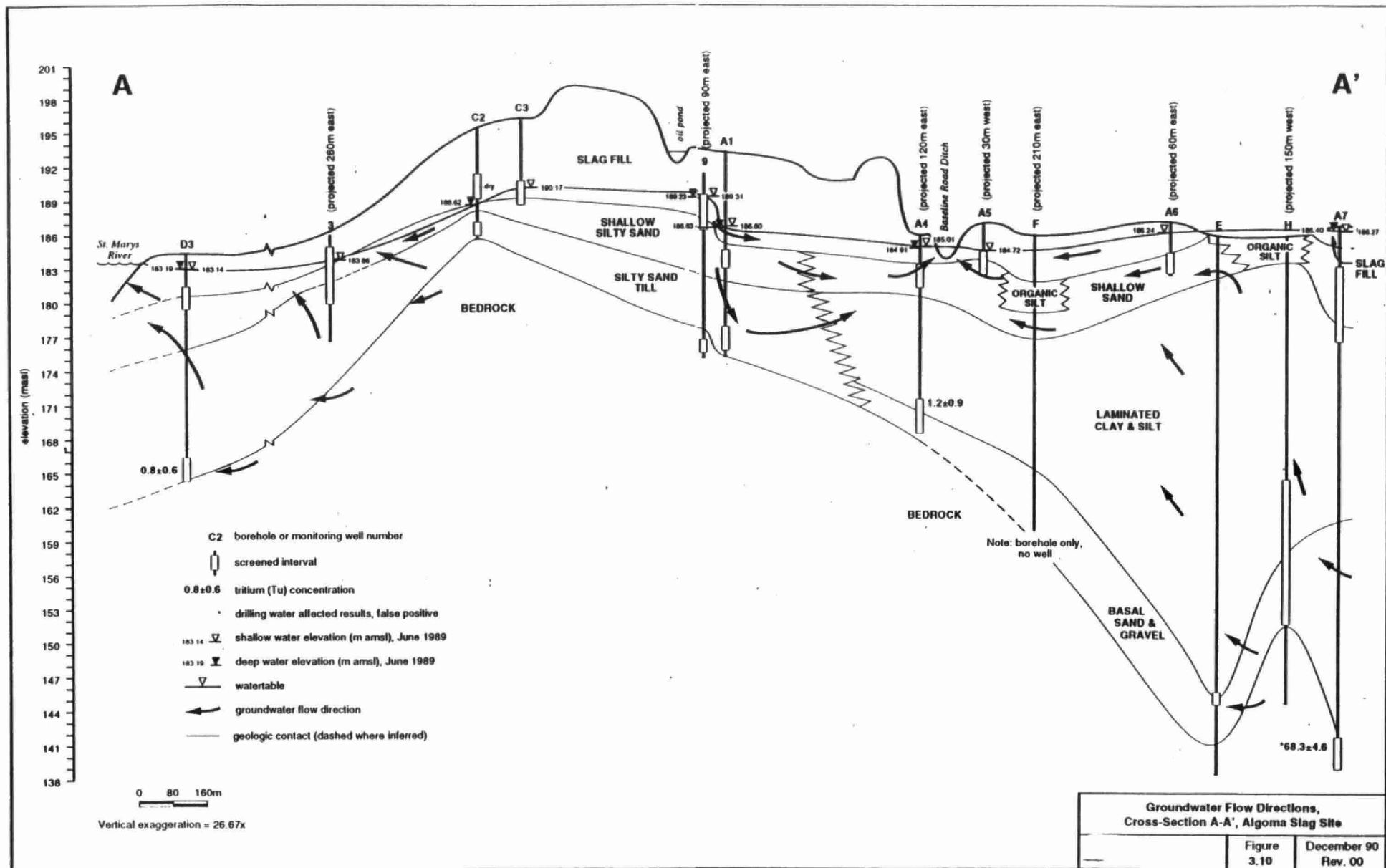
DATA REPRESENTATION

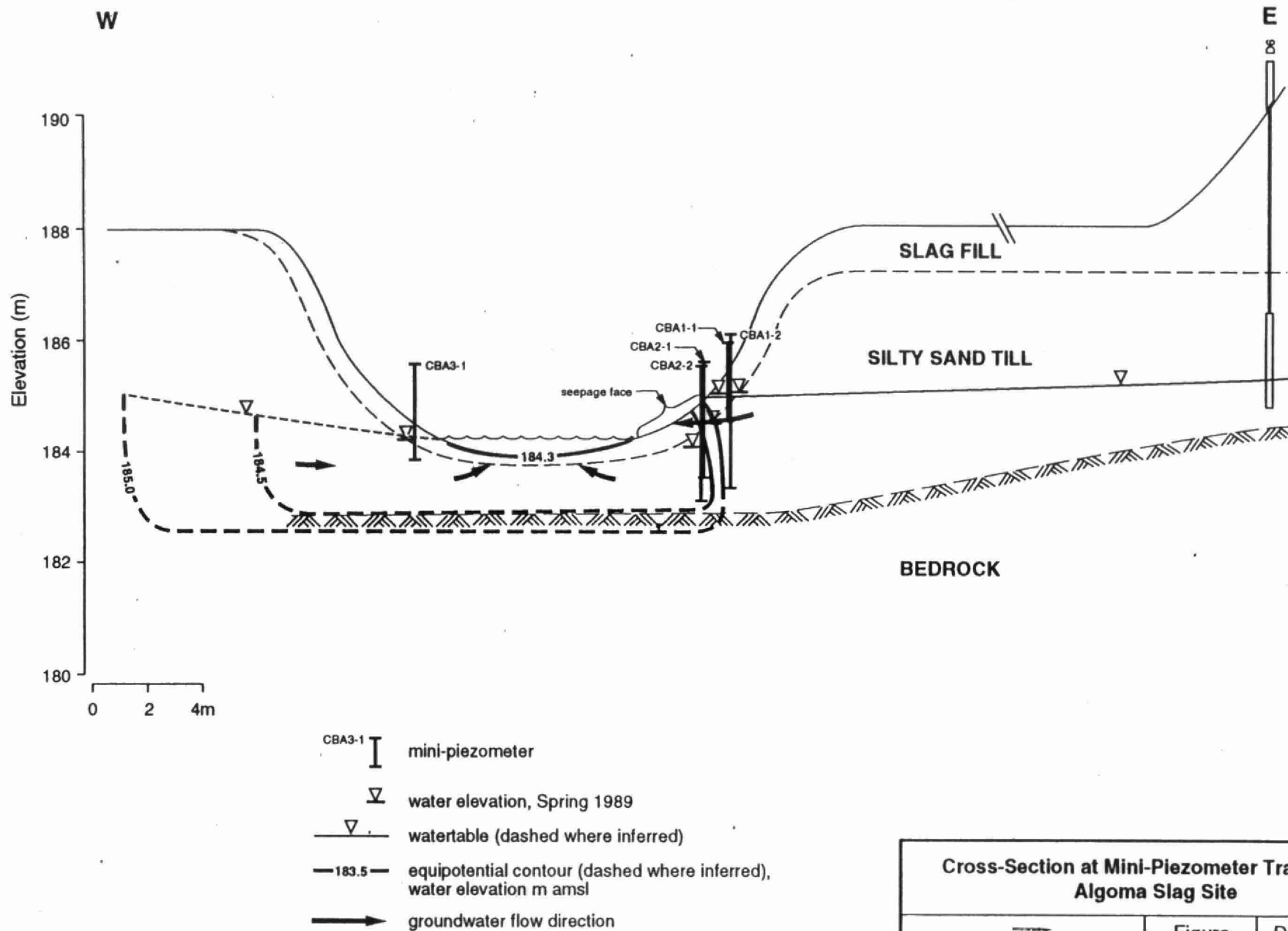
- 180.5 elevation of original ground surface (m amsl)
- (eoh 180.0) original ground surface not encountered, elevation of borehole bottom (m amsl)
- NM not measured
- 182 original ground surface topographic contour

Original Ground Surface Topography,
Algoma Slag Site

Figure 3.8	December 90 Rev. 00
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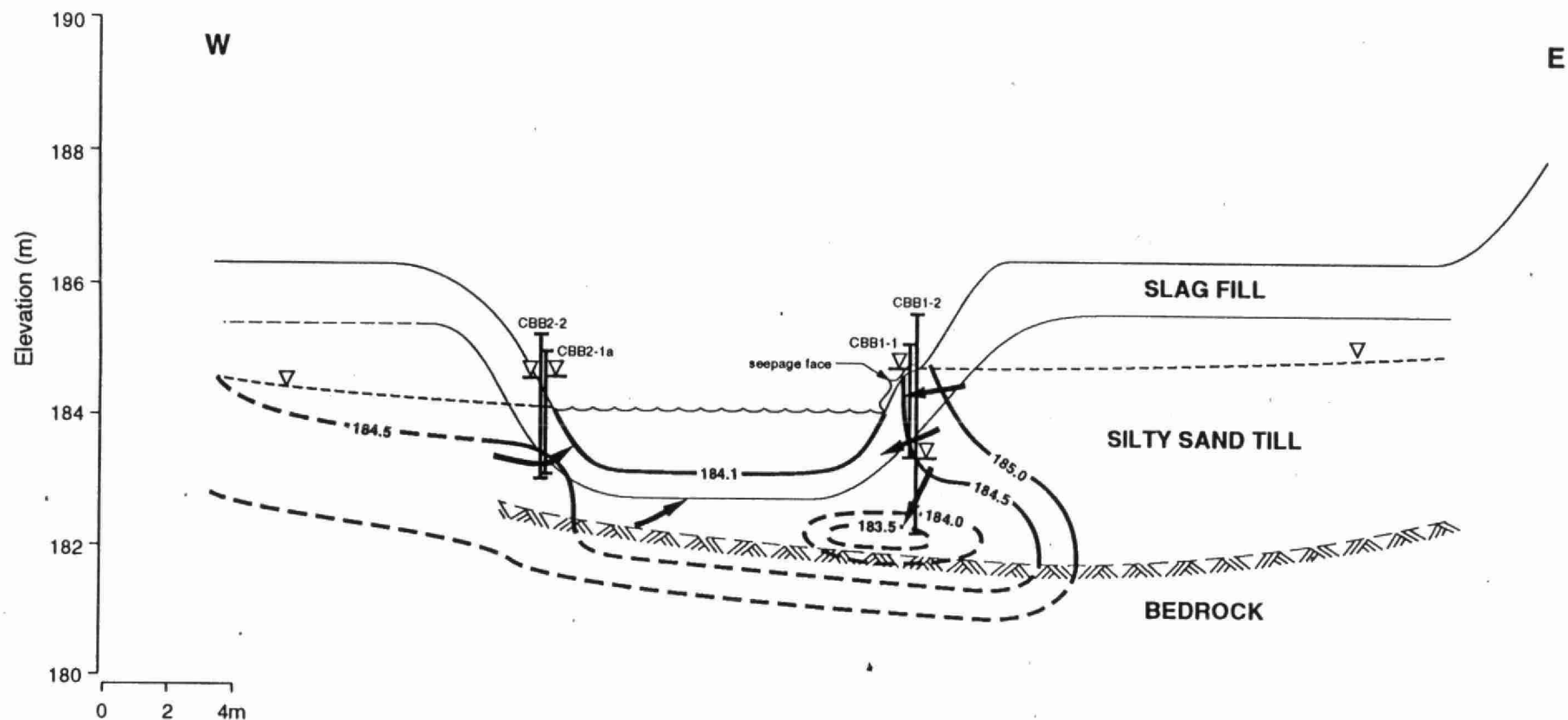




**Cross-Section at Mini-Piezometer Transect A,
Algoma Slag Site**

Figure
3.12

December 90
Rev. 00

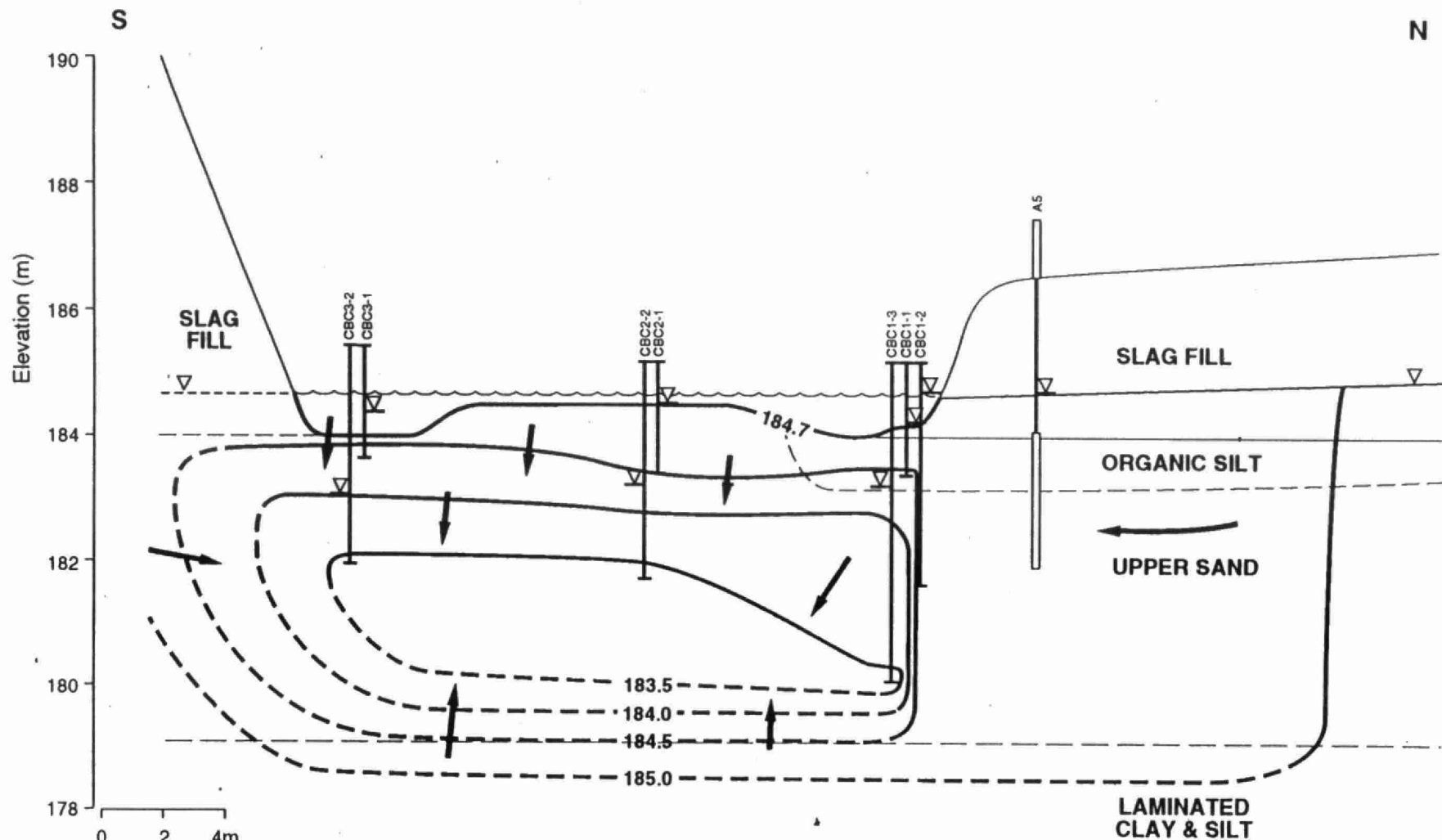


- CBB2-2 I mini-piezometer
 ▽ water elevation, Spring 1989
 - - - water table, Spring 1989 (dashed where inferred)
 —183.5— equipotential contour (dashed where inferred),
 water elevation m amsl
 → groundwater flow direction

Cross-Section at Mini-Piezometer Transect B,
Algoma Slag Site

Figure
3.13

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CBC2-1 I mini-piezometer

▽ water elevation, Spring 1989

▽ watertable (dashed where inferred)

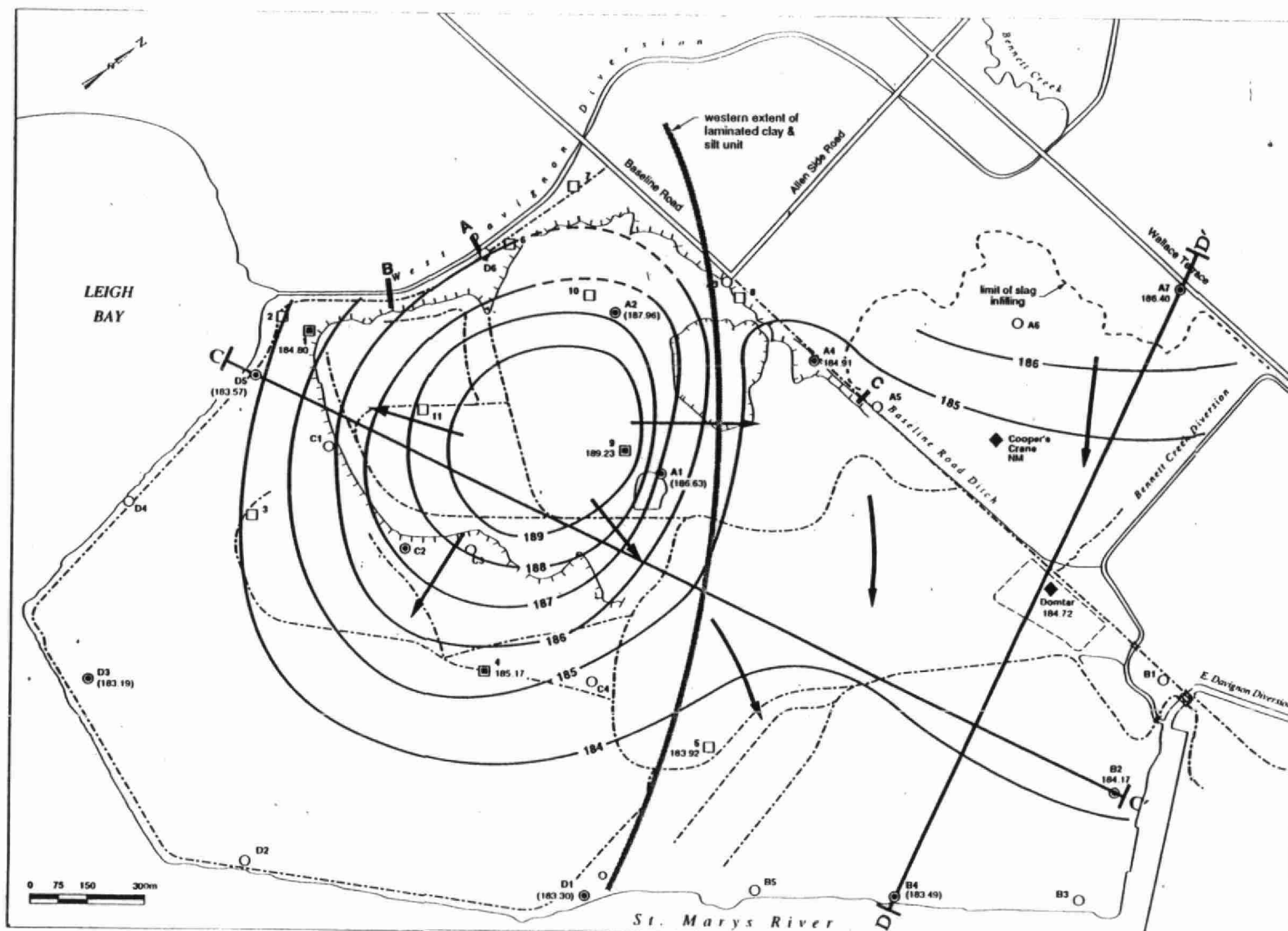
—183.5— equipotential contour (dashed where inferred),
water elevation m amsl

→ groundwater flow direction

Cross-Section at Mini-Piezometer Transect C,
Algoma Slag Site

Figure
3.14

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Rev. 00



- gravel road
- - - fence
- - - escarpment/depression
- C H C cross-section location

INSTRUMENTATION

BEAK Wells (1988)

- monitoring well
- ⊙ monitoring well nest

Geocon Wells (1983)

- monitoring well
- ⊠ monitoring well nest

on-site water supply wells

- ◆ on-site water supply wells
- A creek bed mini-piezometer transect location

DATA REPRESENTATION

185.05 confined aquifer water elevation (m amsl),
01 June 1989

(185.63) aquitard water elevation (m amsl),
01 June 1989

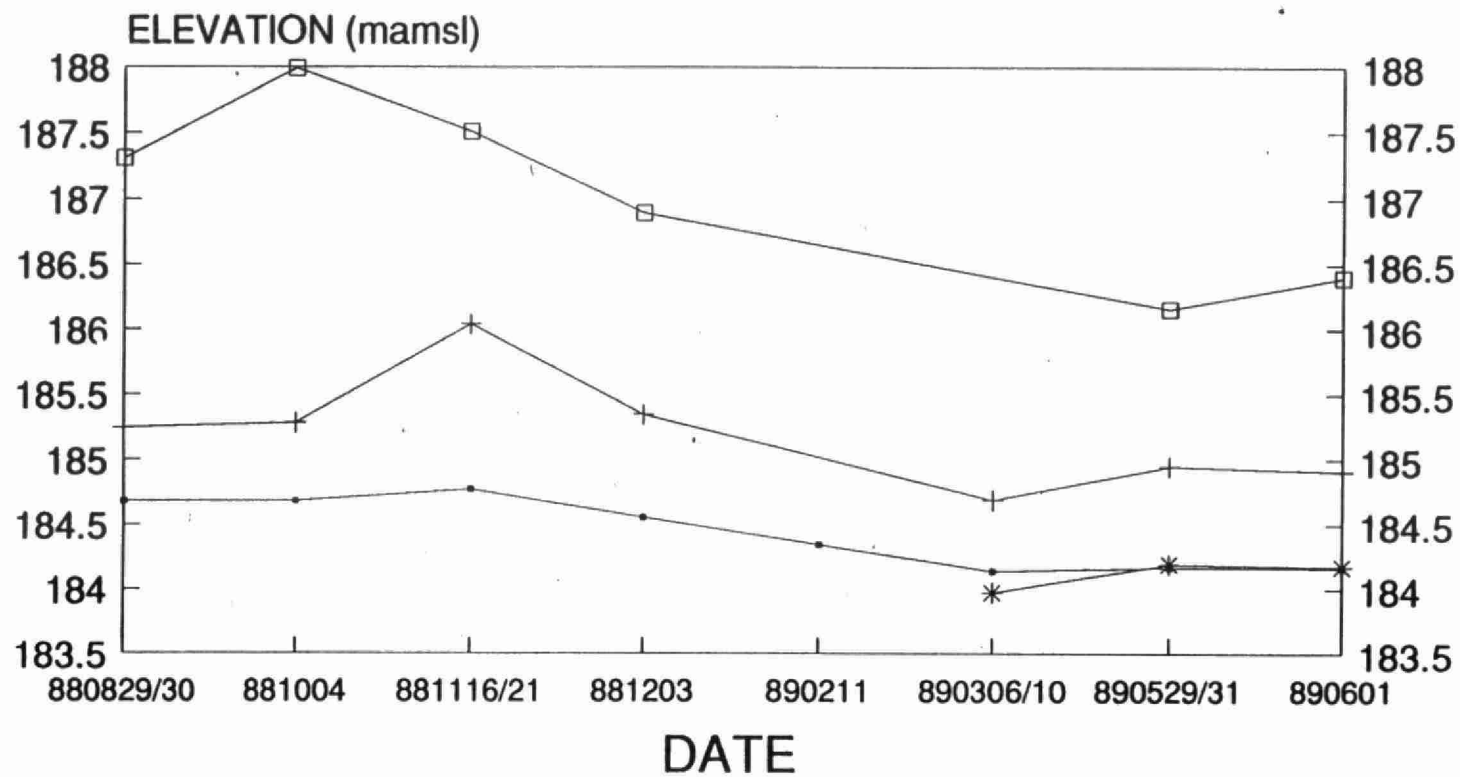
NM not measured

185 — confined aquifer potentiometric contour

→ direction of groundwater flow

Confined Aquifer Potentiometric Surface,
Algoma Slag Site

December 90
Rev. 00

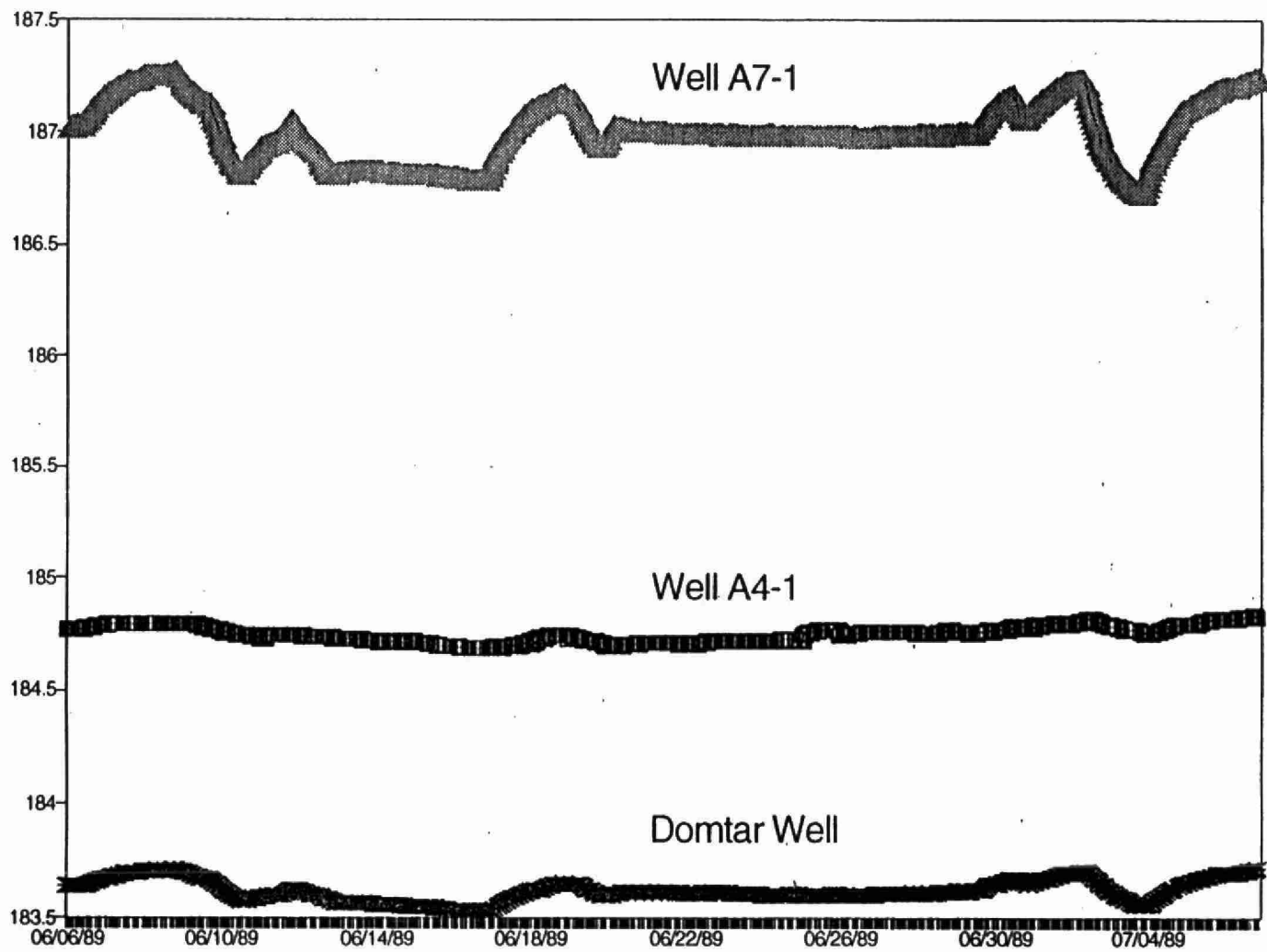


—•— B2-1 —+— A4-1 —*— B2-3 —□— A7-1

**Water Elevation Data for Confined Aquifer
Monitoring Wells, Algoma Slag Site**

Figure
3.16

December 90
Rev. 00

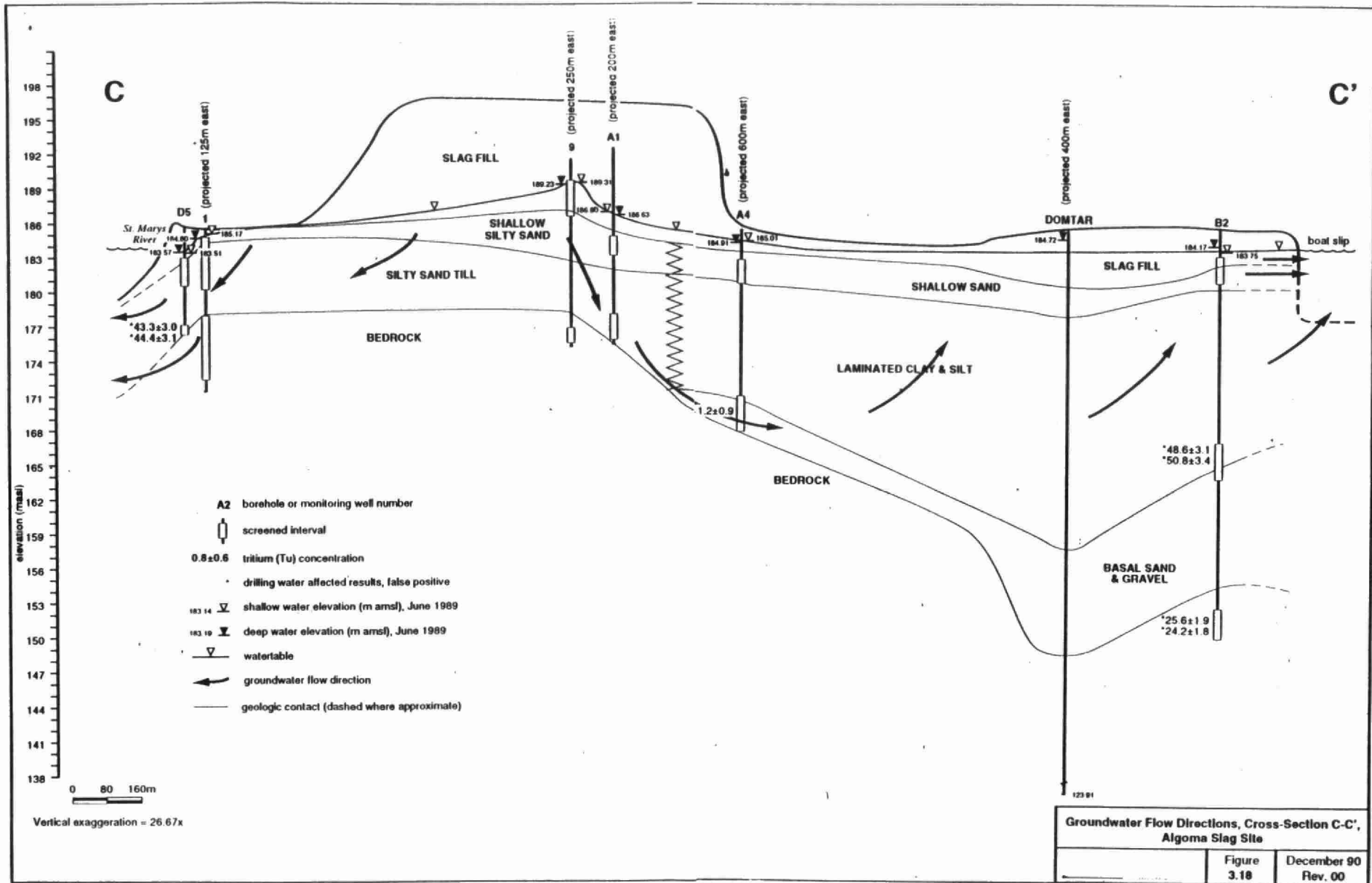


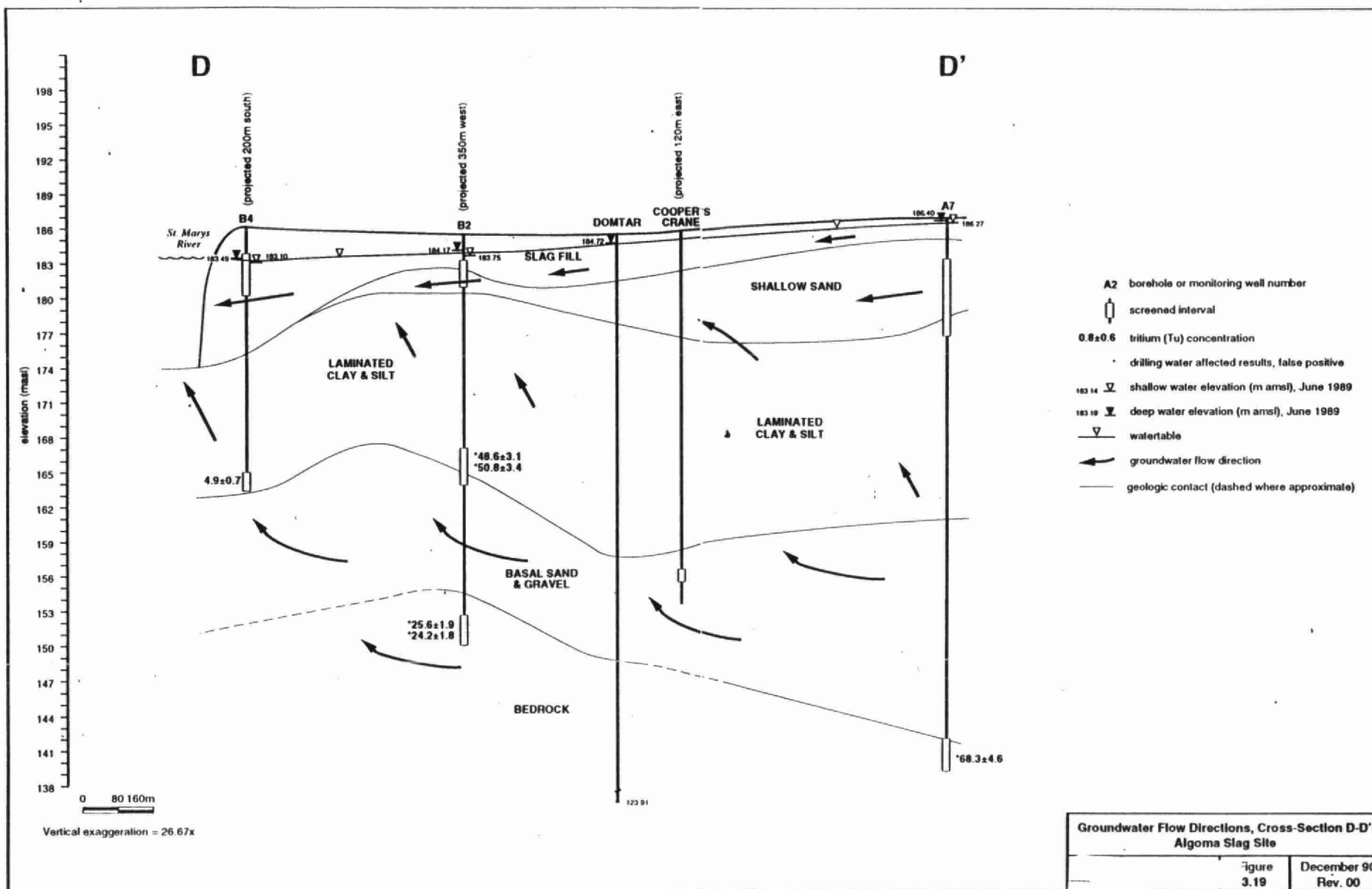
Hourly Water Level Measurements,
Confined Aquifer, Algoma Slag Site

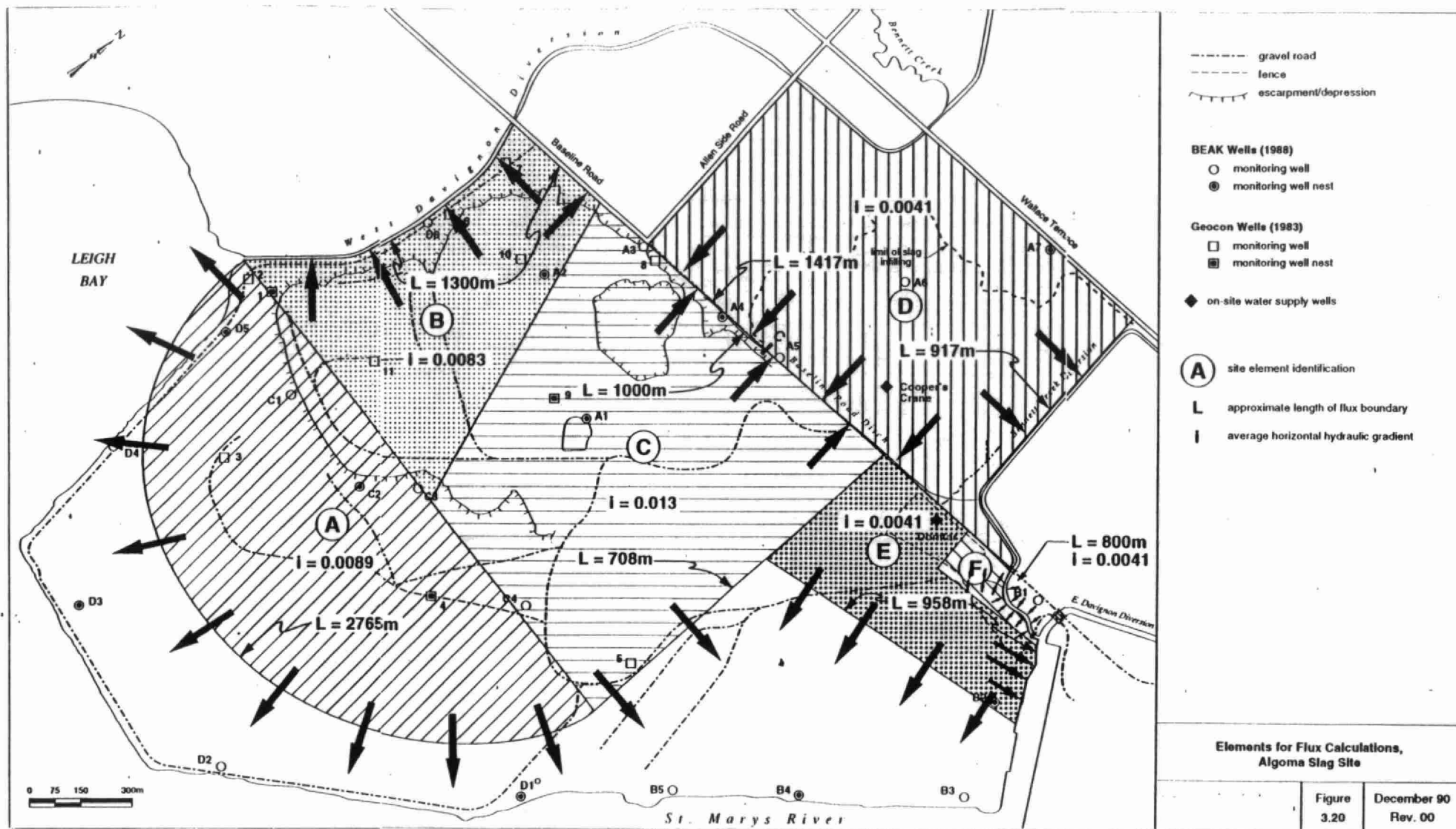
e

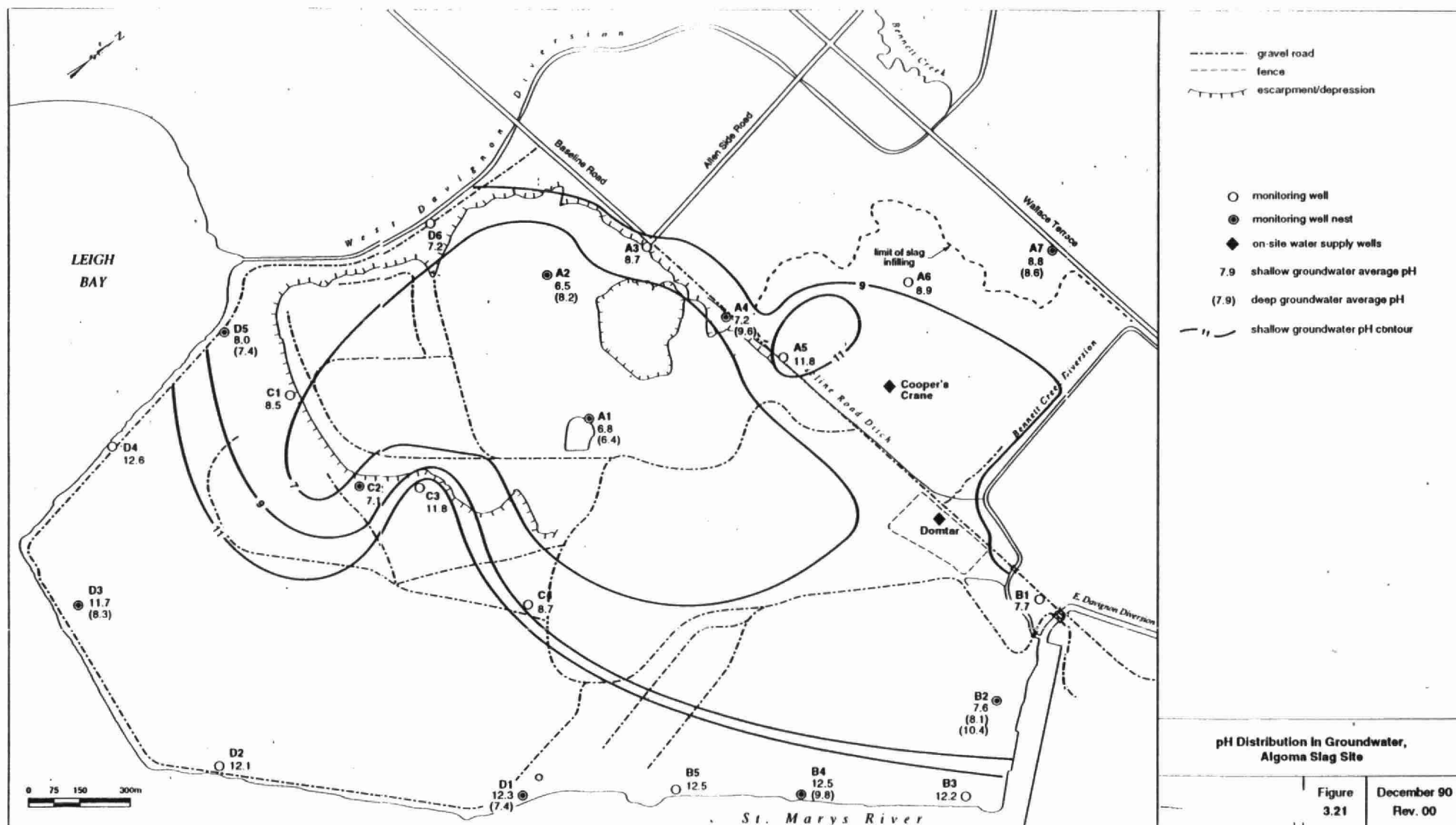
7

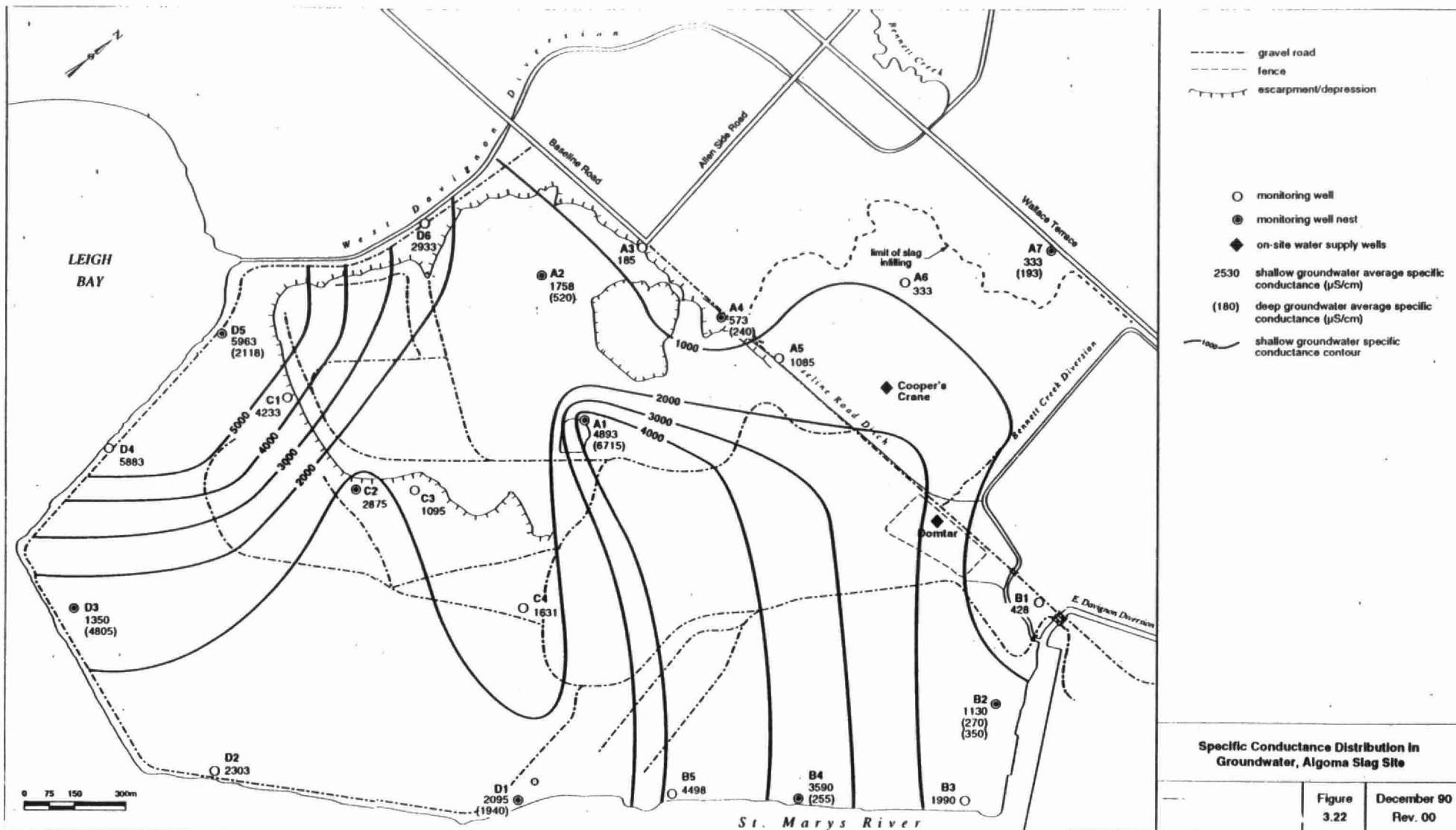
December 90
Rev. 00

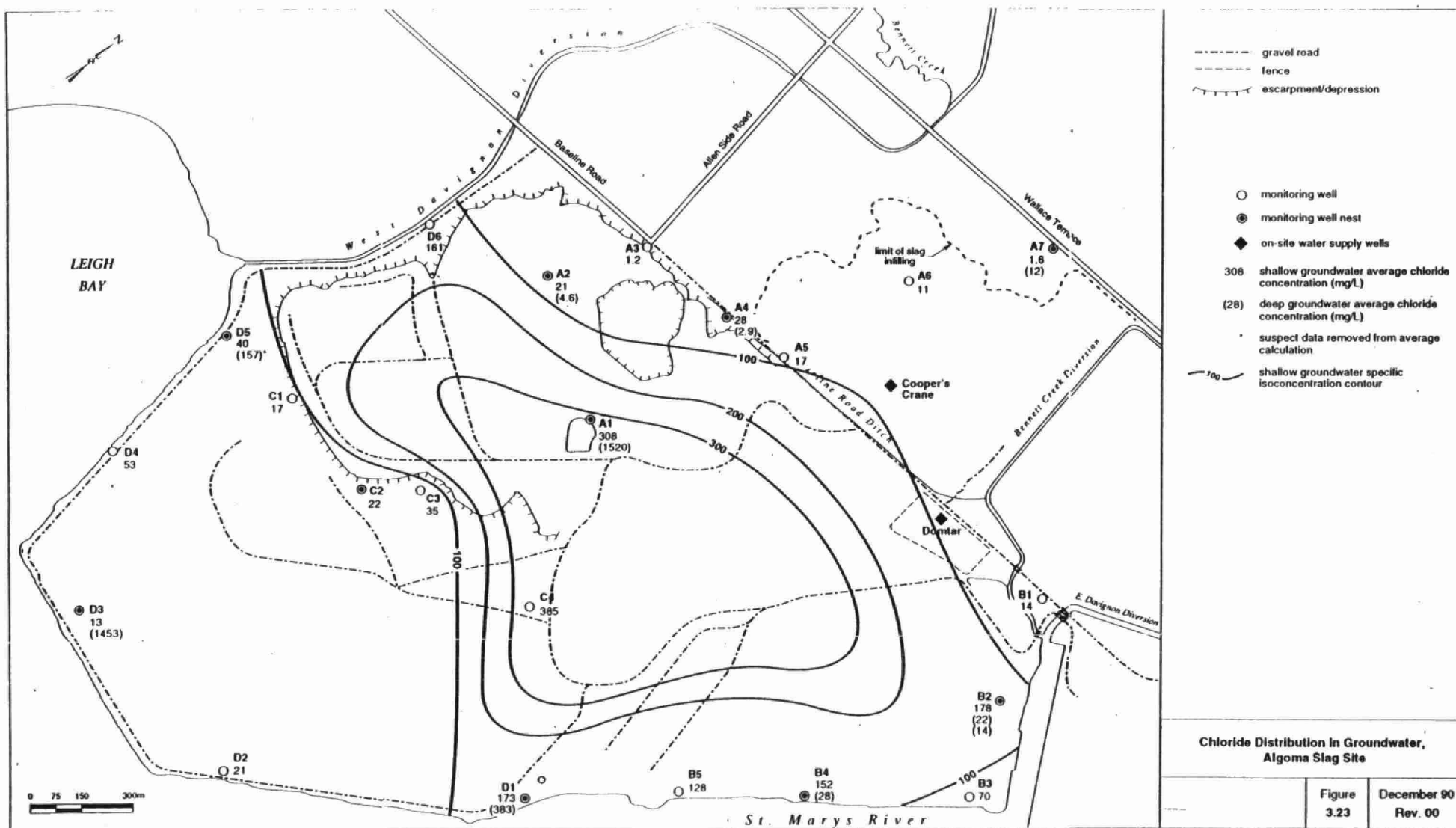


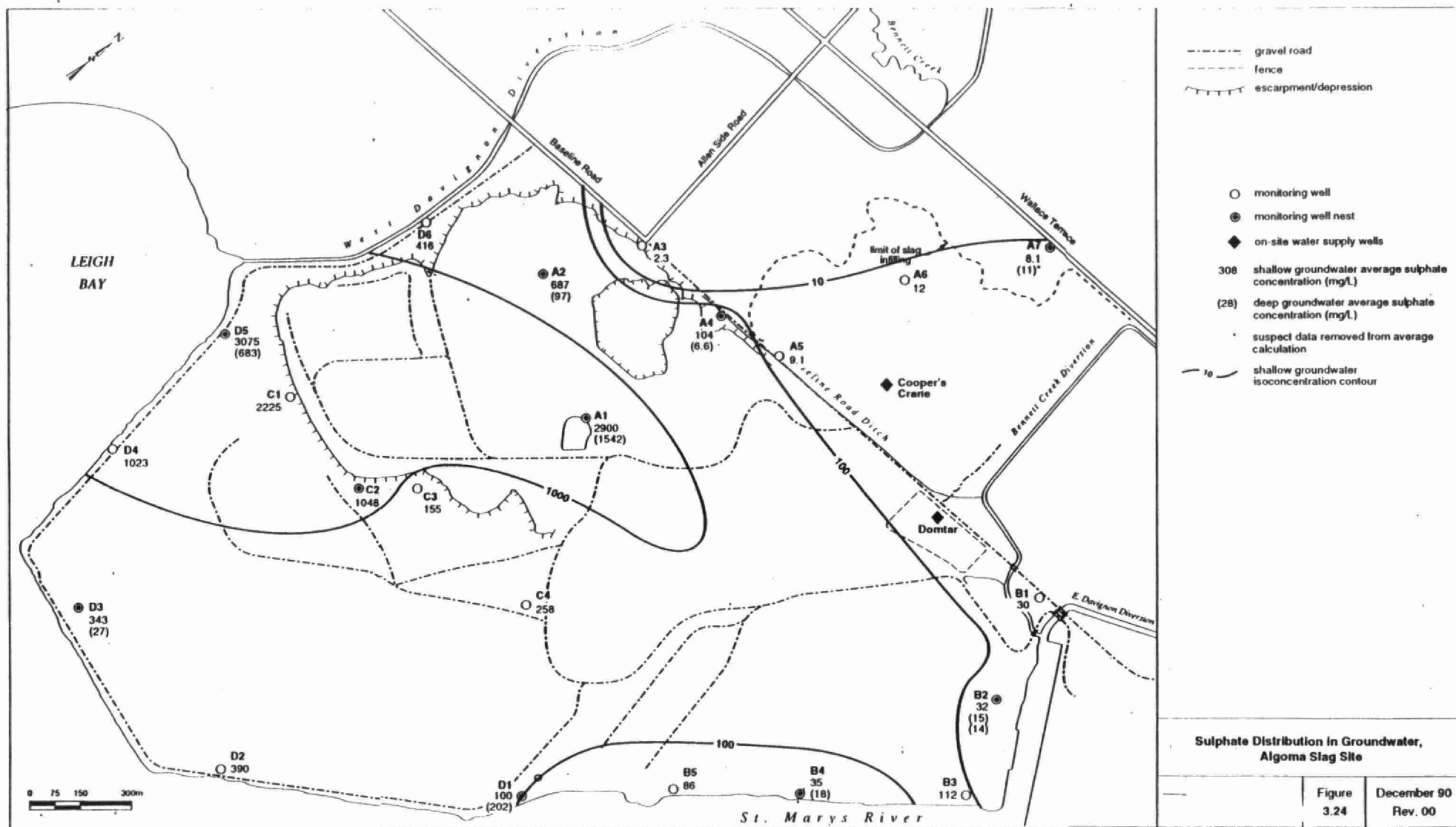


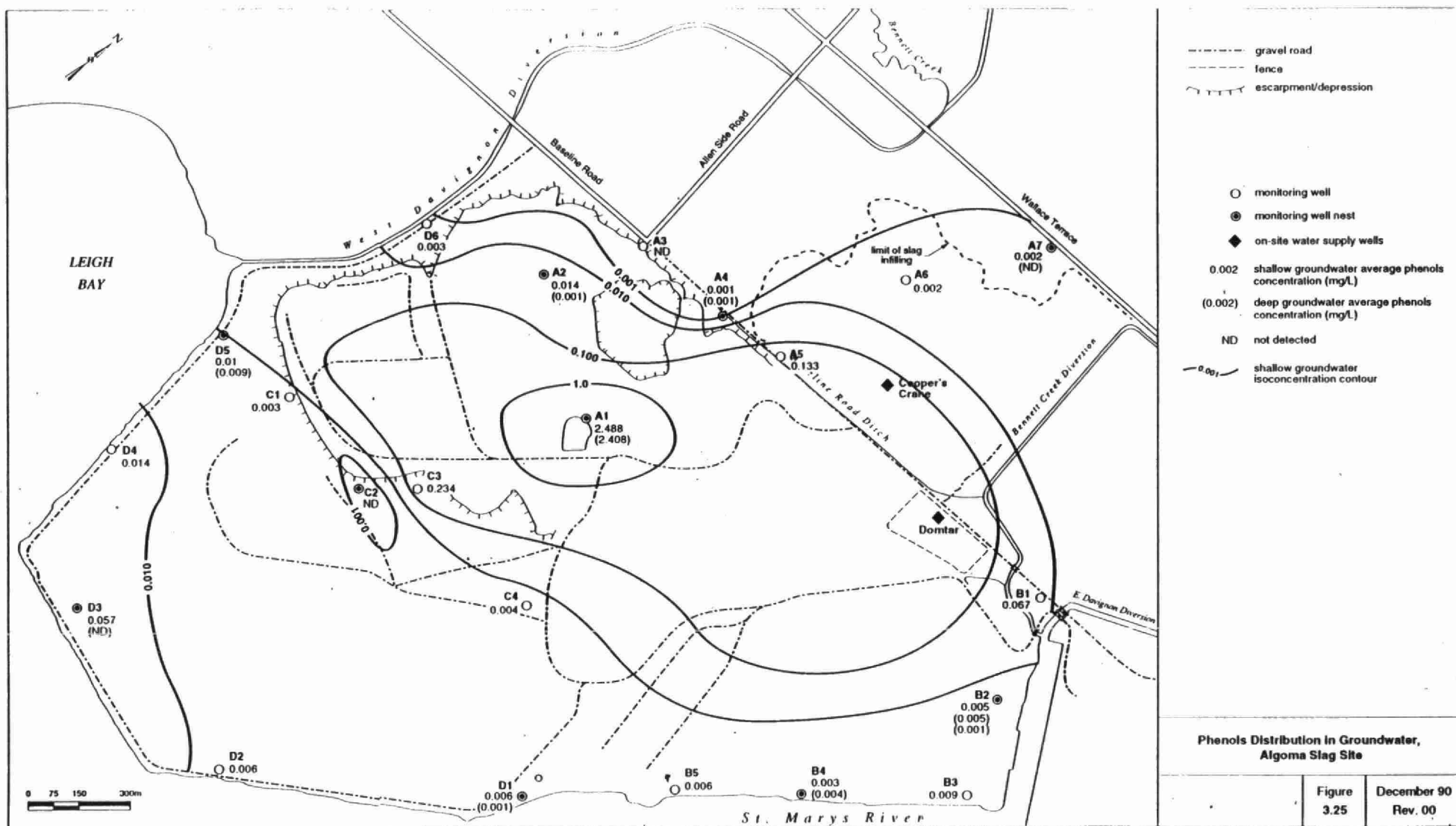


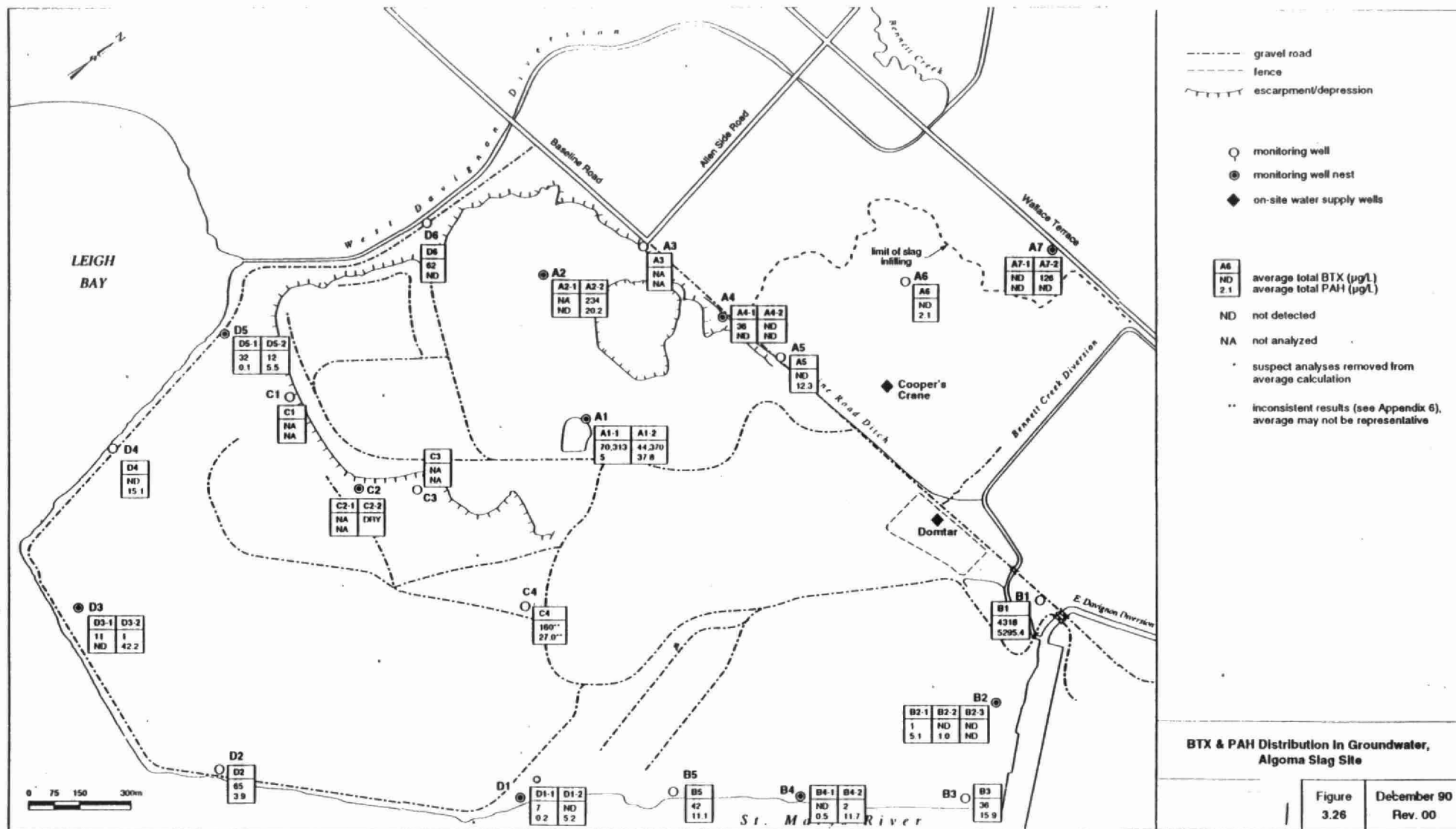


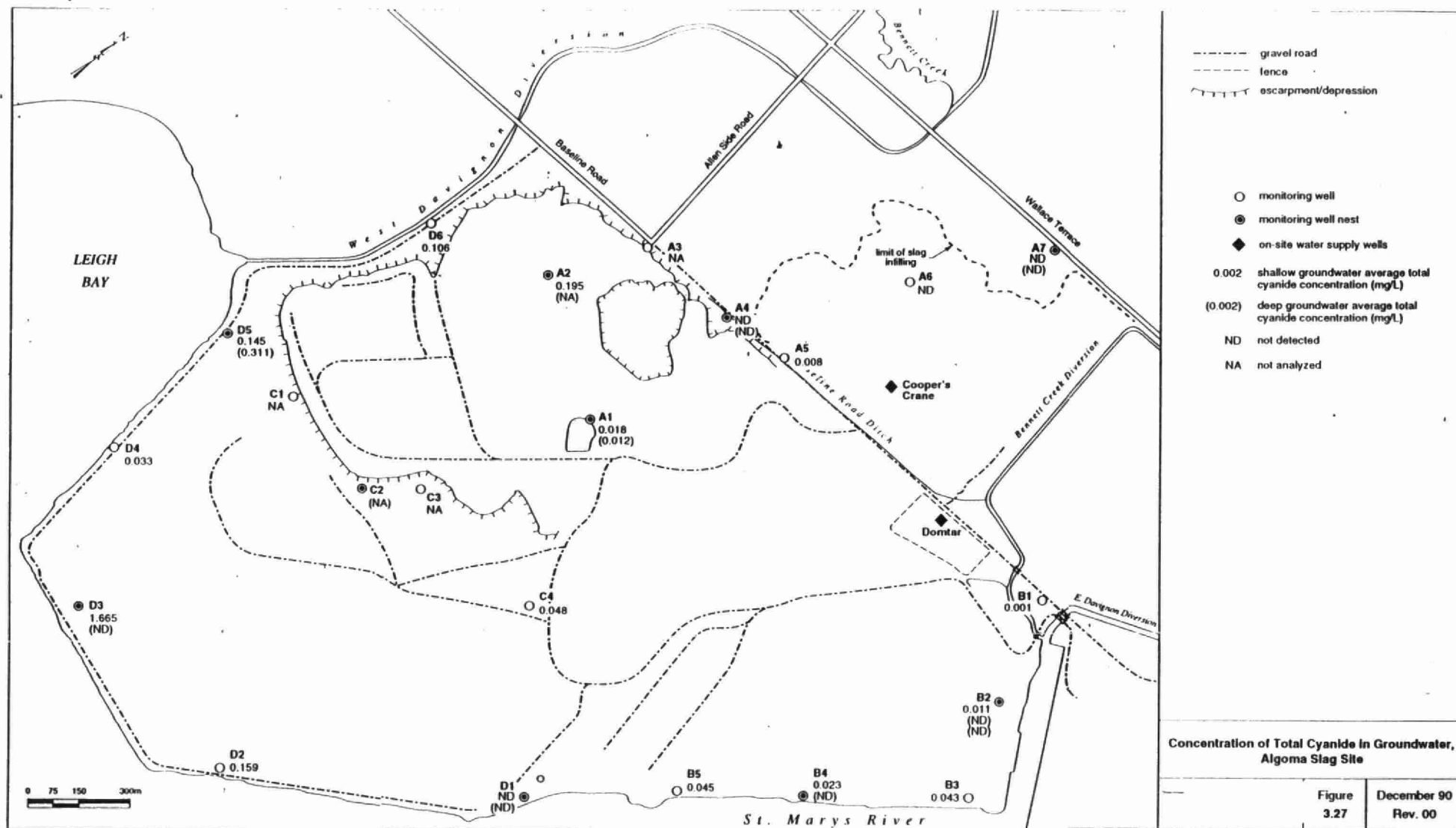


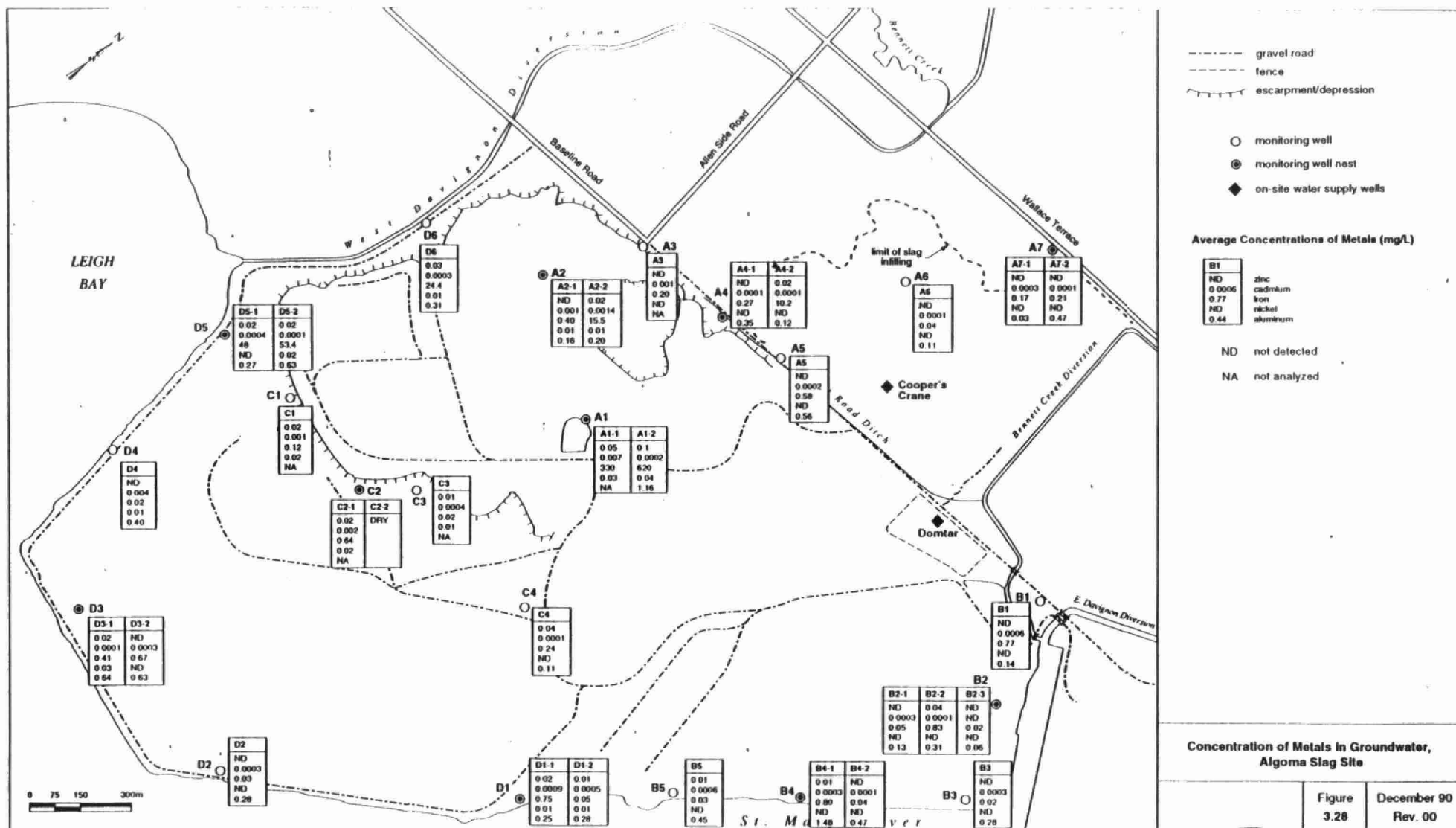


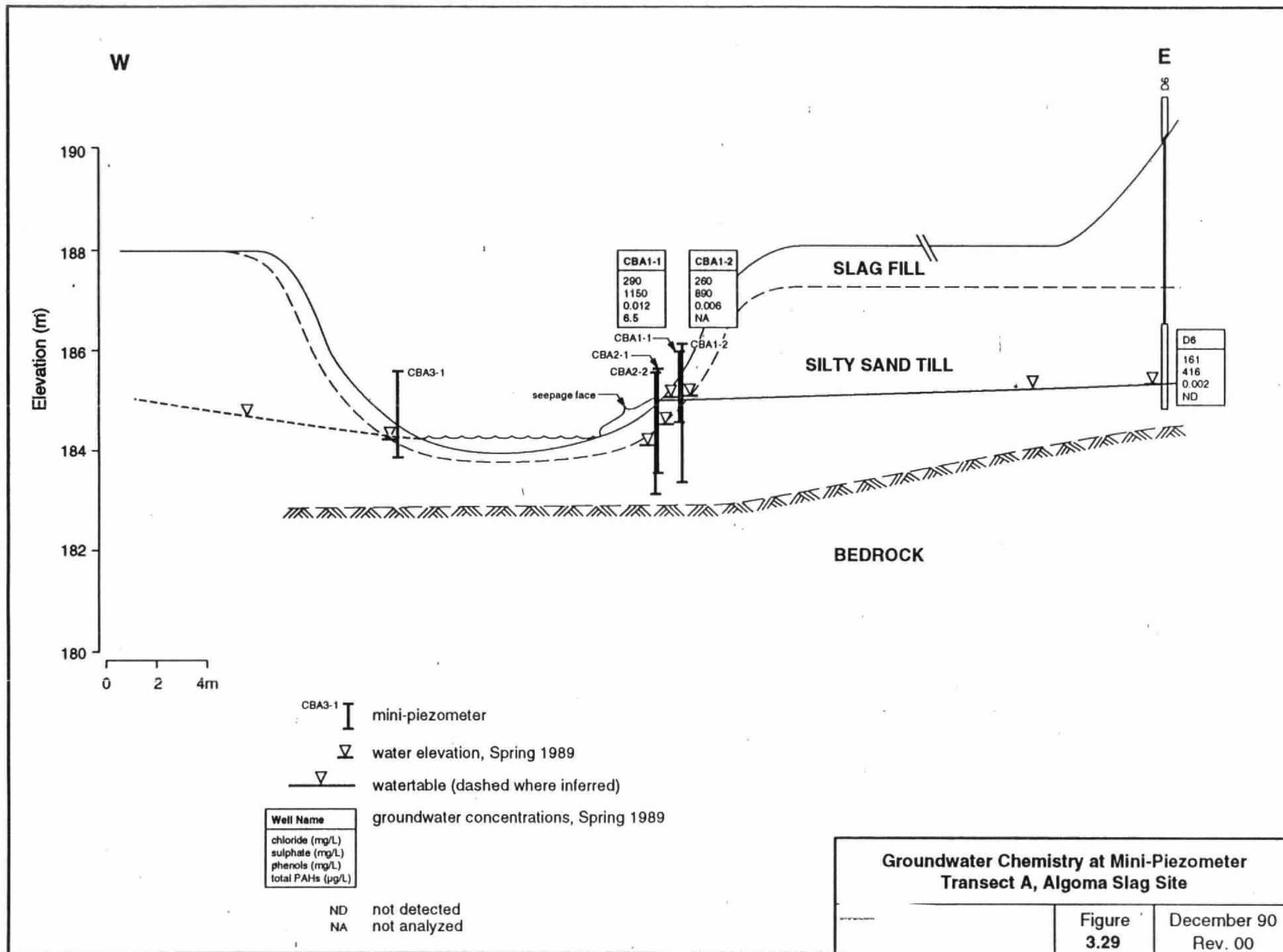


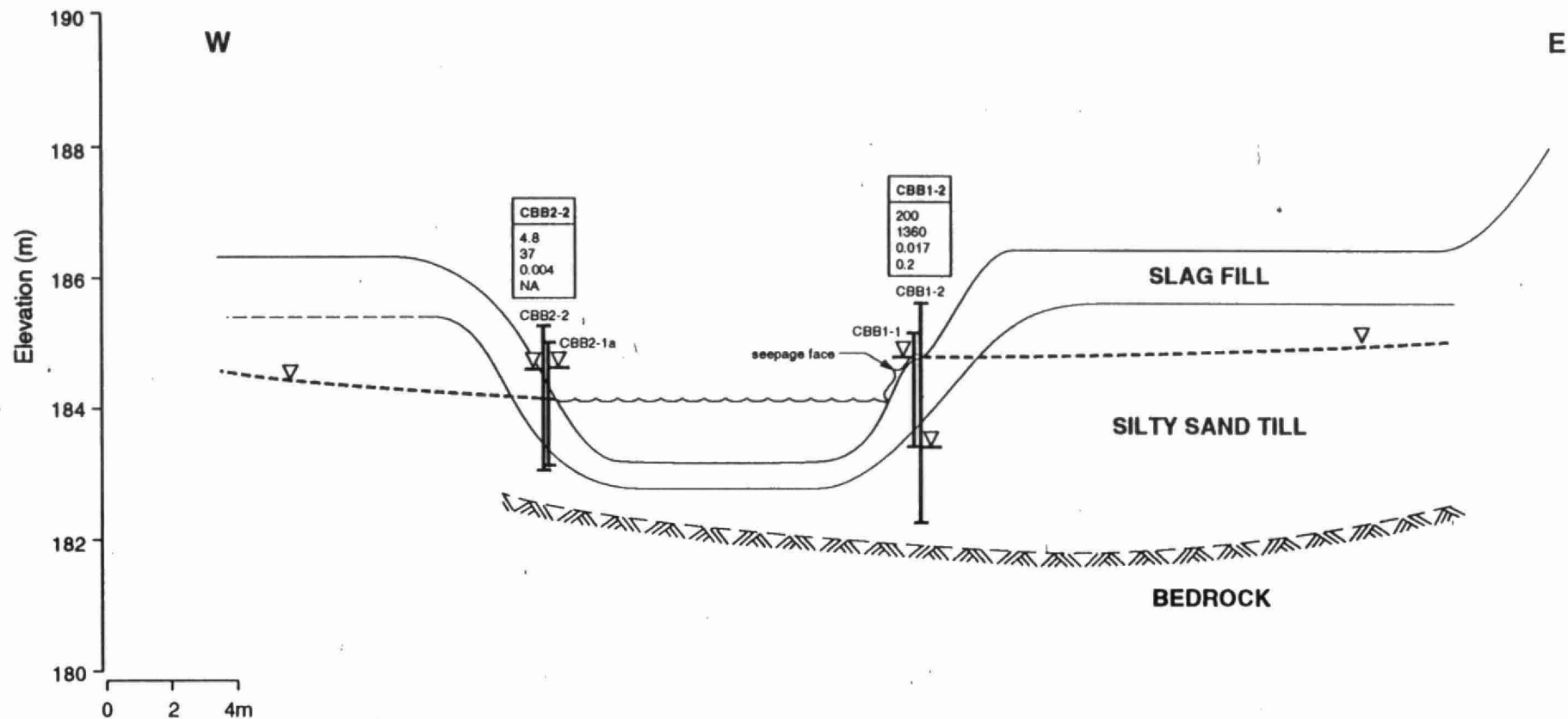


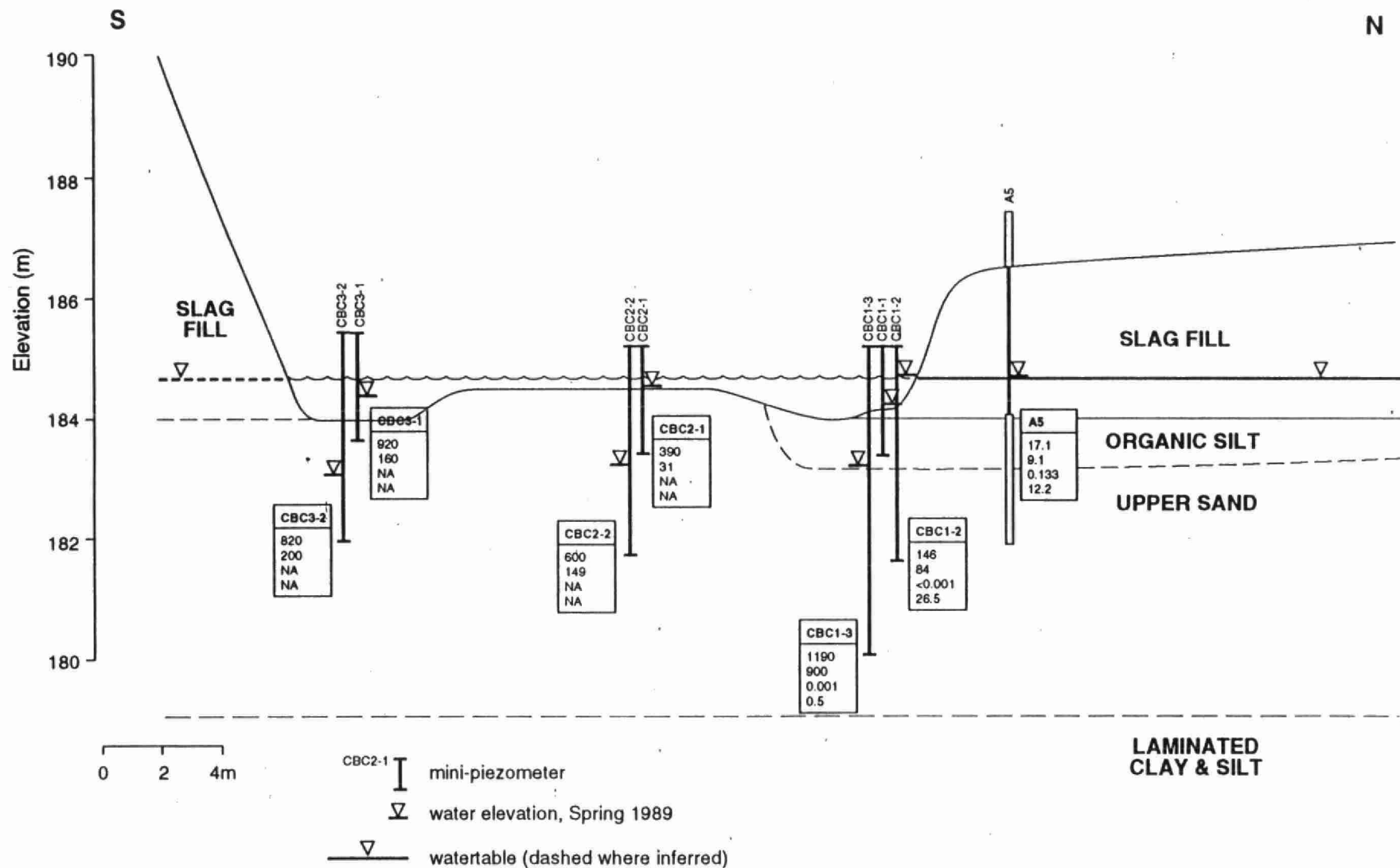








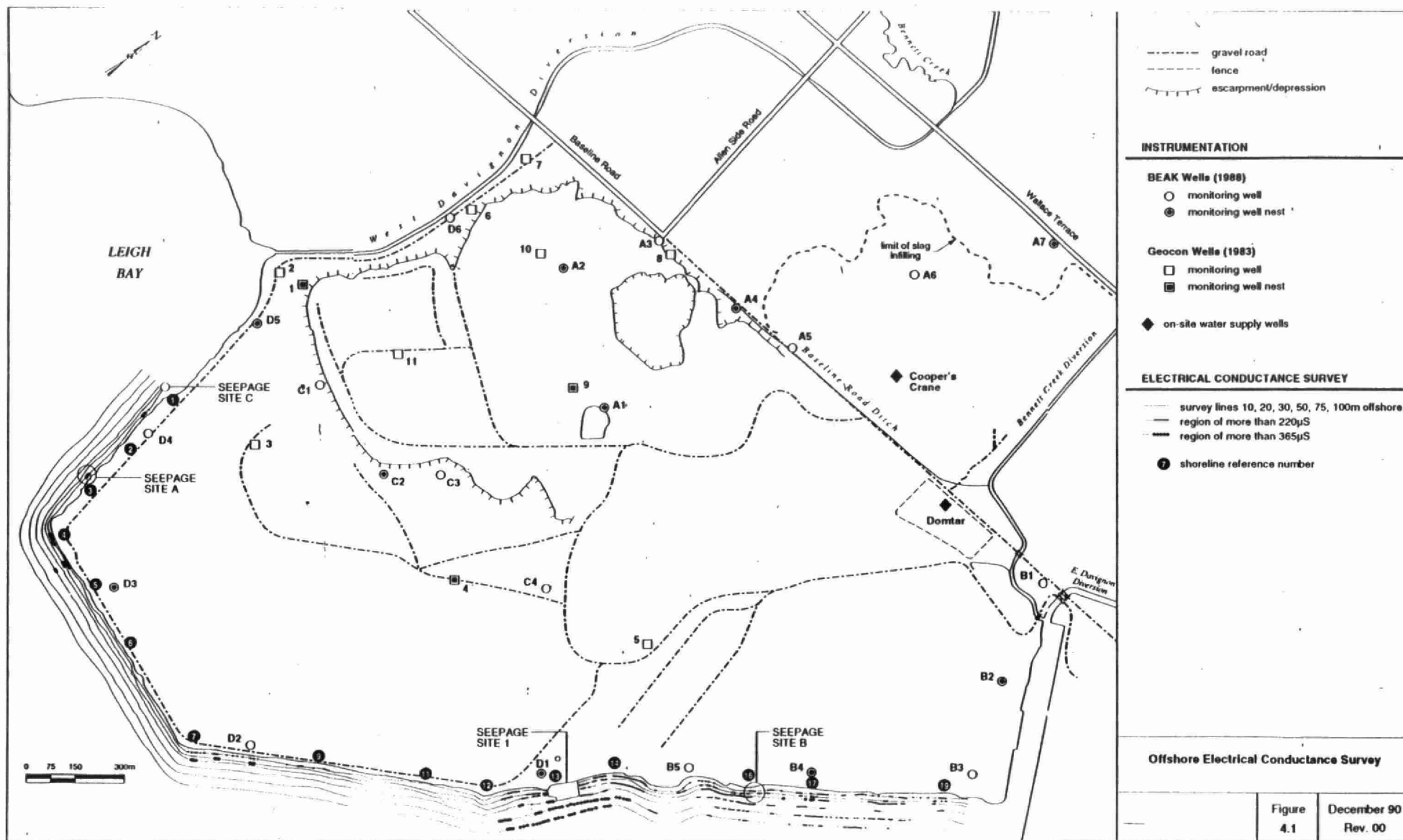


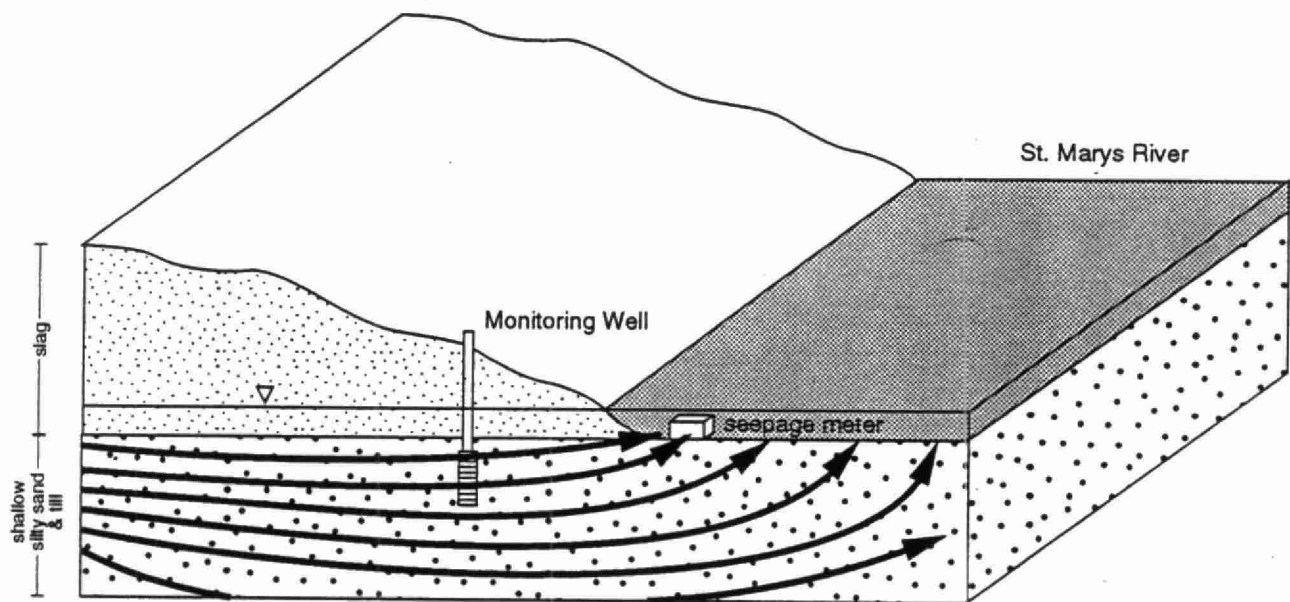


Groundwater Chemistry at Mini-Piezometer Transect C, Algoma Slag Site

Figure
3.31

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Rev. 00

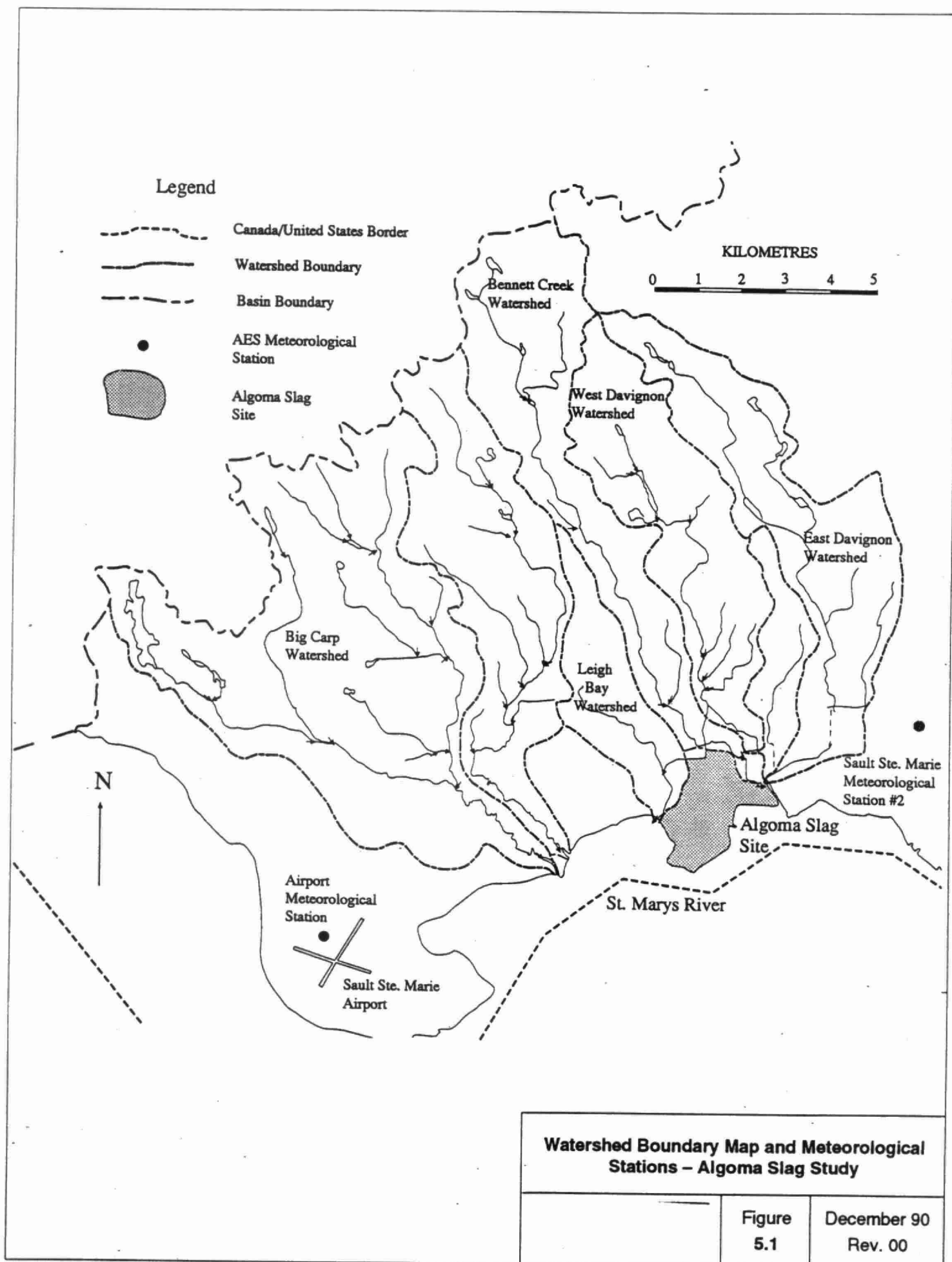


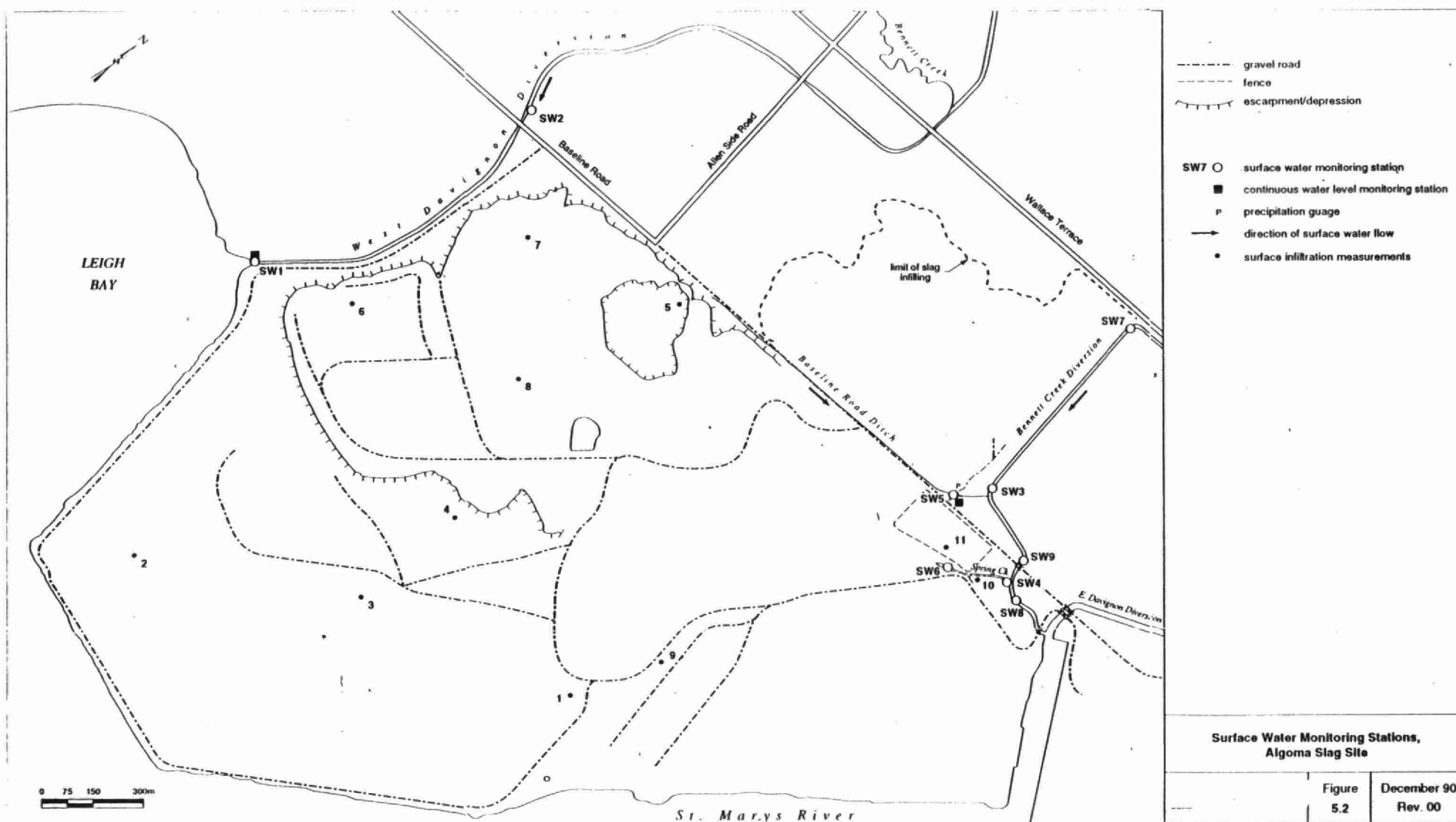


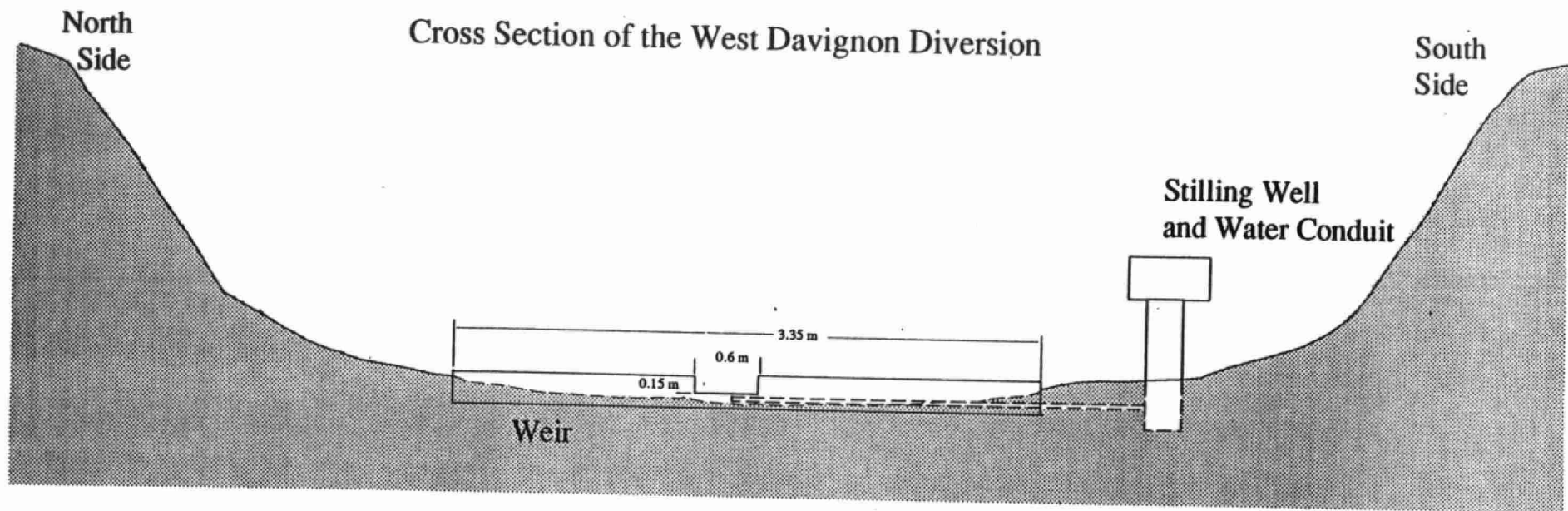
Schematic Seepage Block Diagram

Figure
4.2

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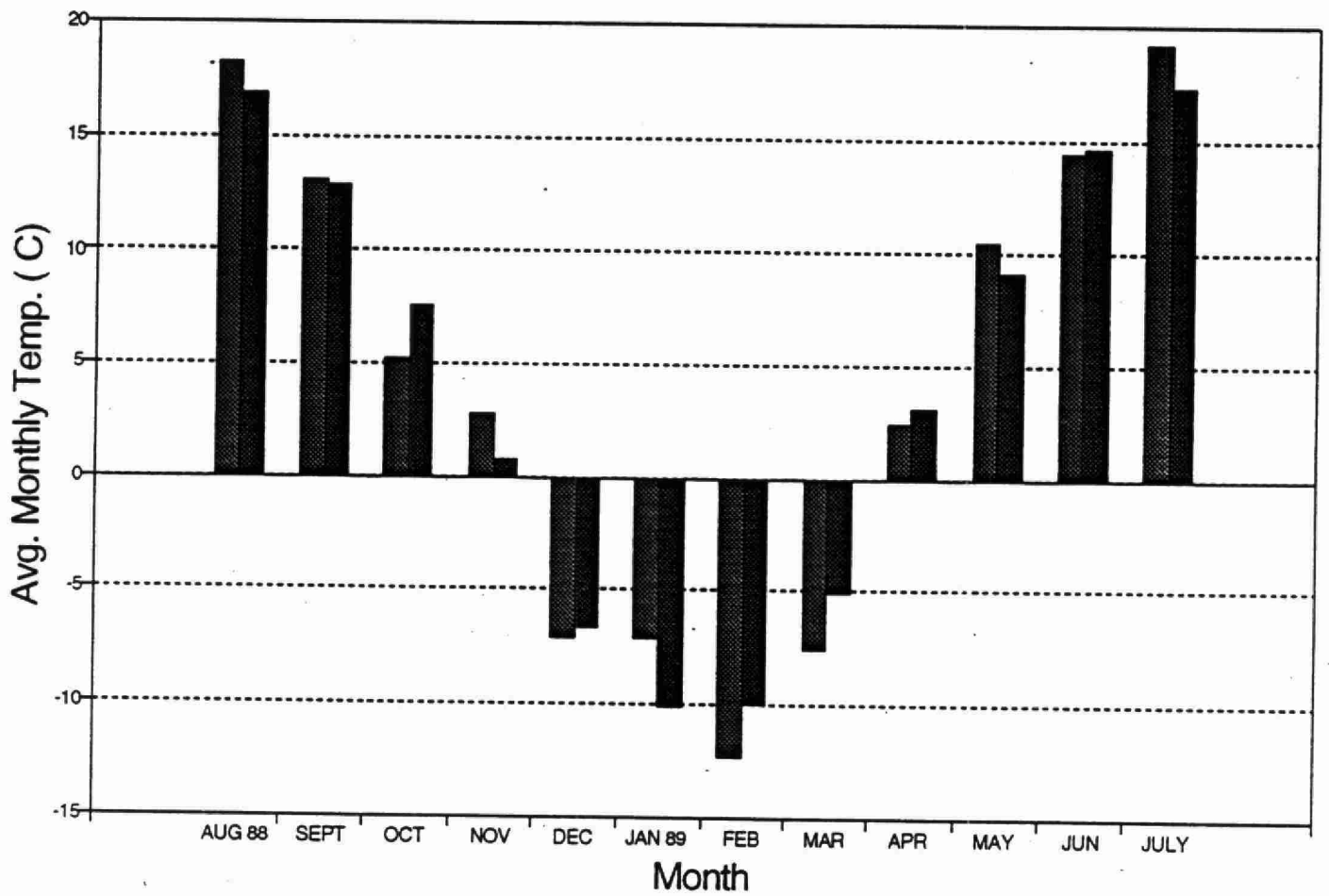




**Schematic Diagram of Weir Structure Used at
Surface Water Monitoring Station SW1**

Figure
5.3

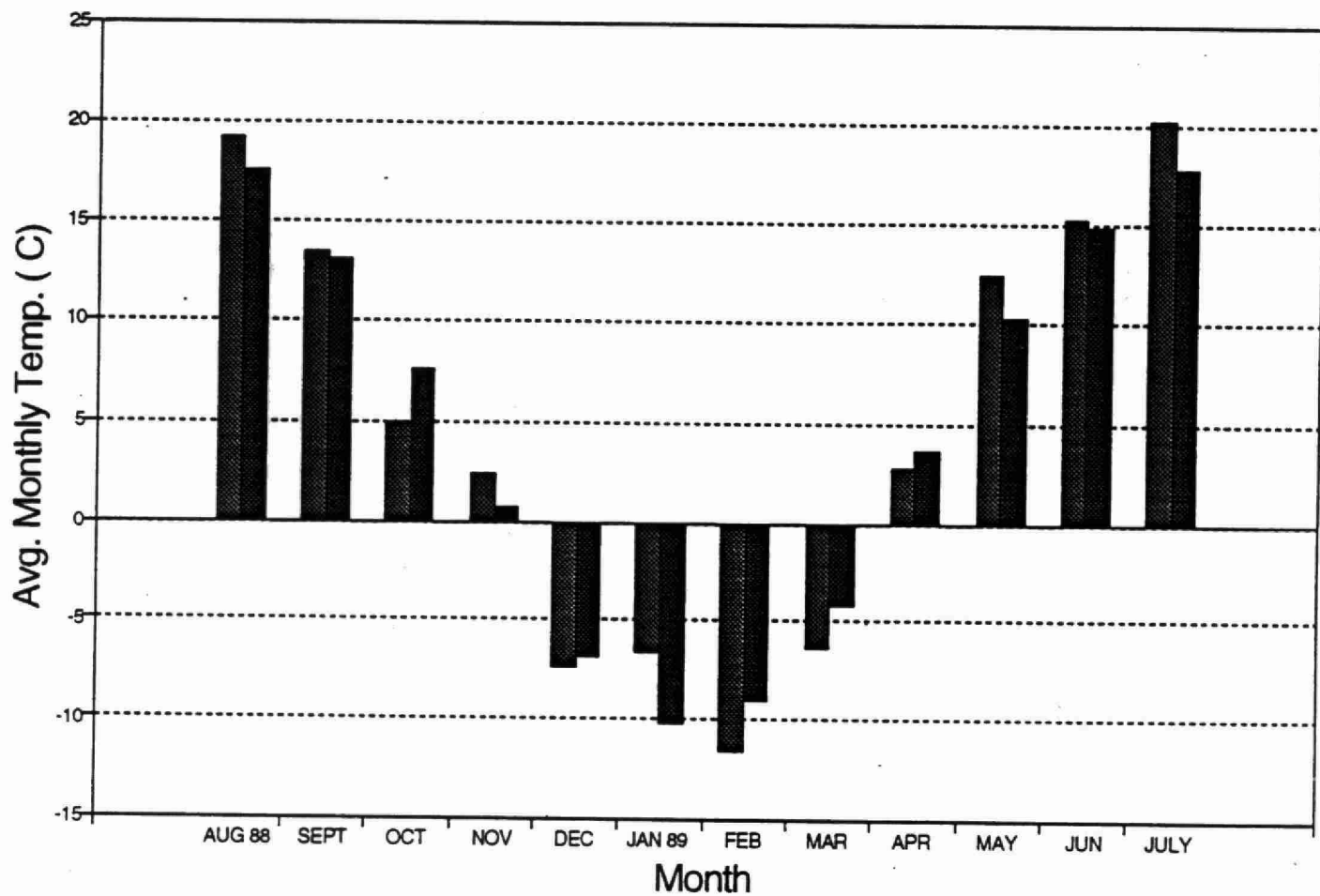
December 90
Rev. 00



Average Monthly Air Temperature,
Sault Ste. Marie Airport

Figure
5.4

December 90
Rev. 00

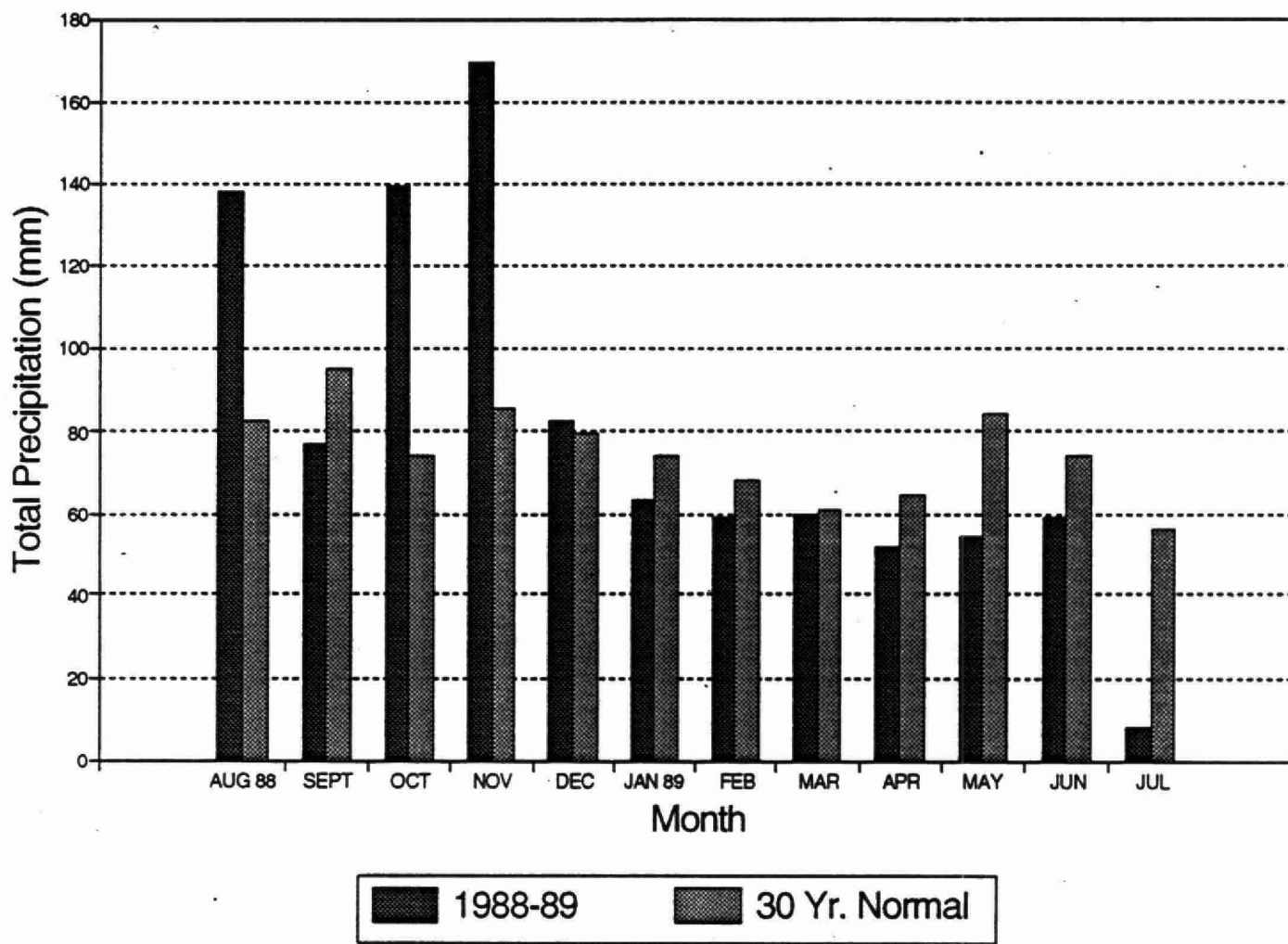


1988-1989 30 Yr. Normal

Average Monthly Air Temperature,
Sault Ste. Marie Station 2

Figure
5.5

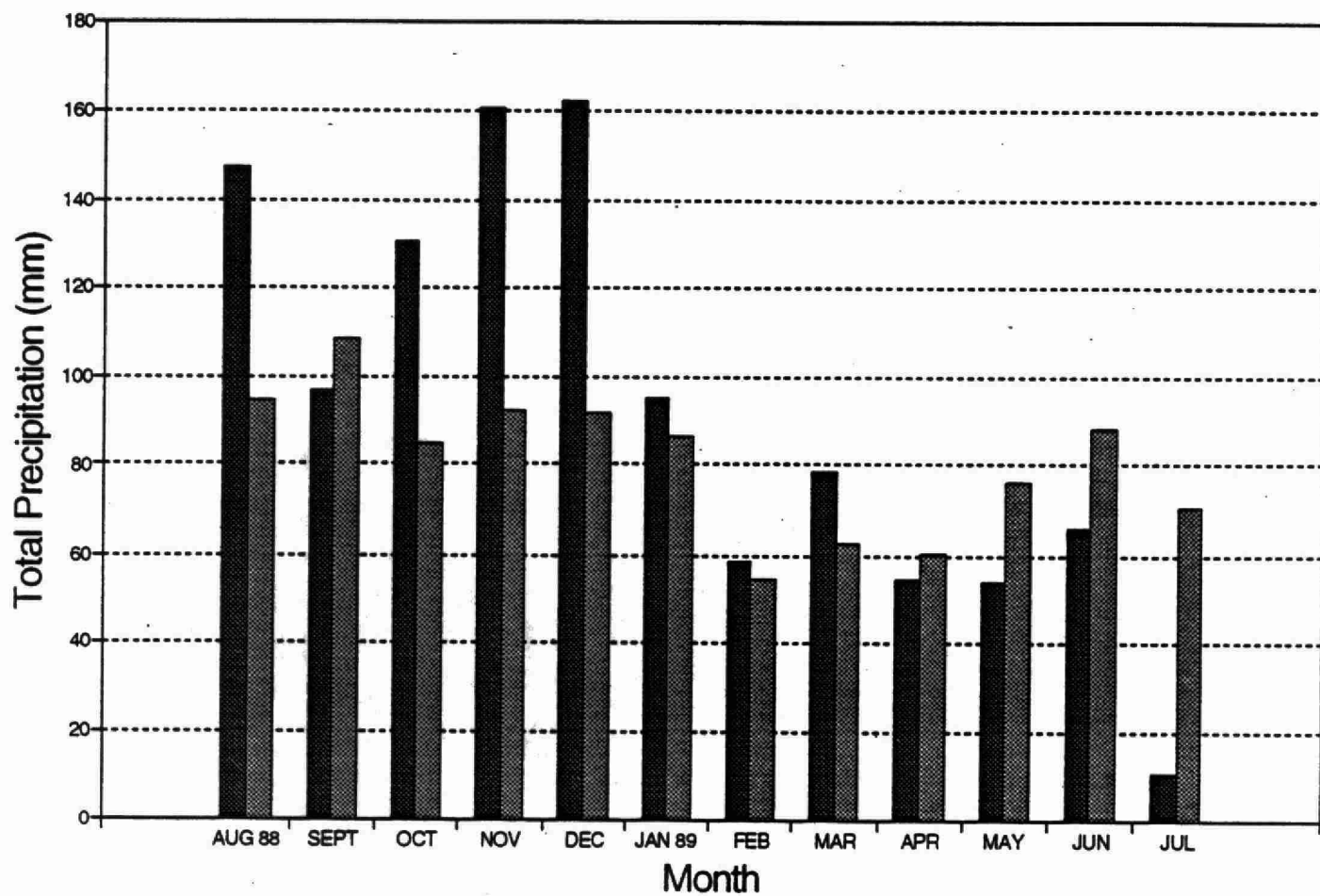
December 90
Rev. 00



**Total Monthly Precipitation,
Sault Ste. Marie Airport**

Figure
5.6

December 90
- Rev. 00

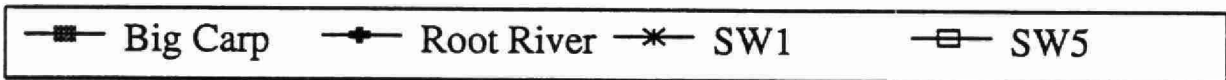
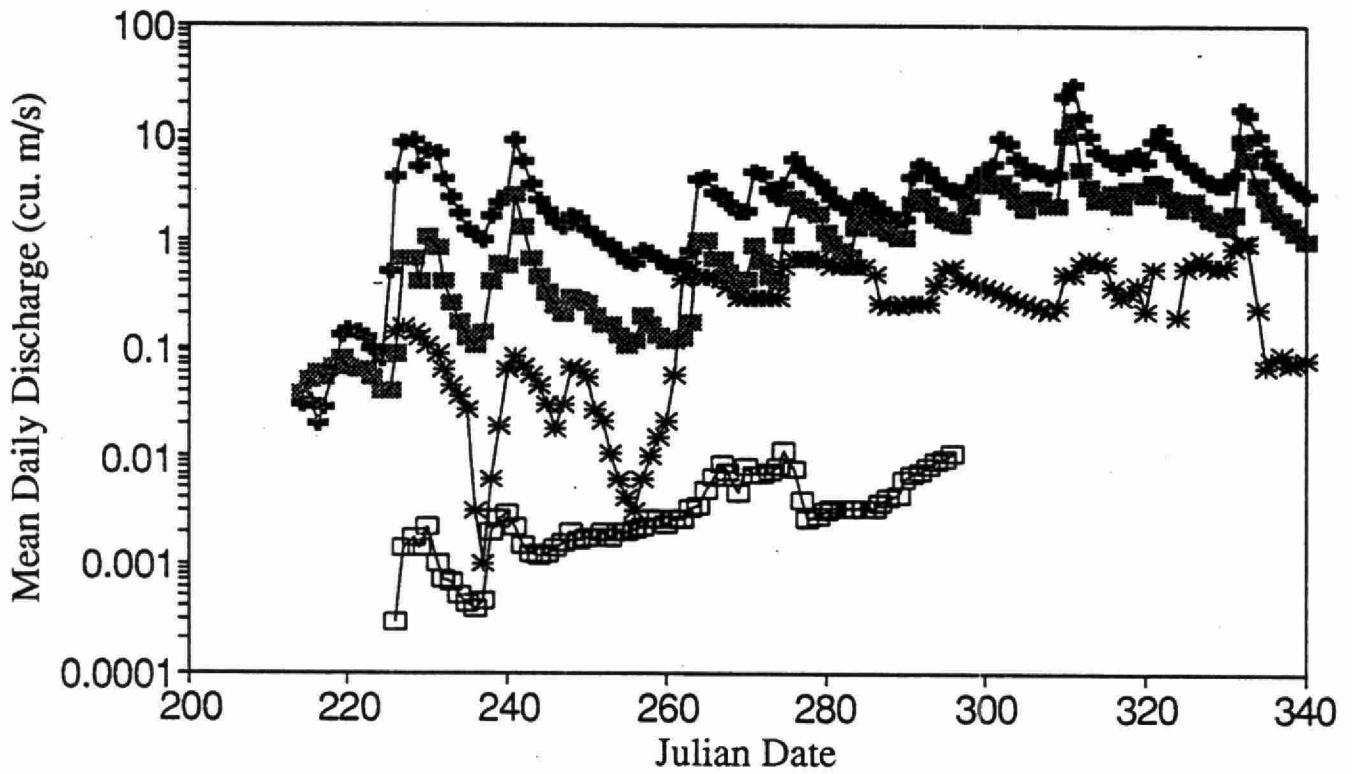


**Total Monthly Precipitation,
Sault Ste. Marie Station 2**

Figure
5.7

December 90
Rev. 00

1988

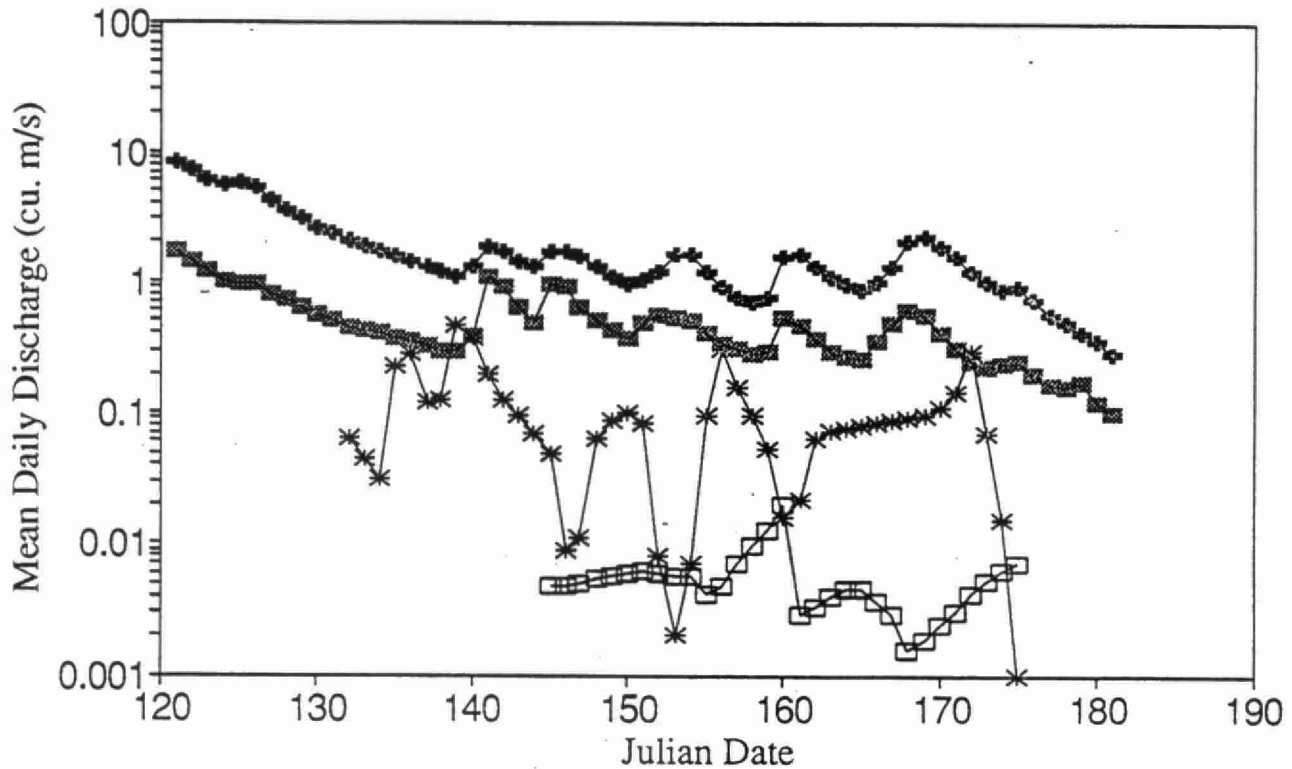


Mean Daily Flow at Monitoring Stations
SW1 (West Davignon), SW5 (Baseline Road
Ditch), Big Carp River and Root River, 1988

Figure
5.8

December 90
Rev. 00

1989



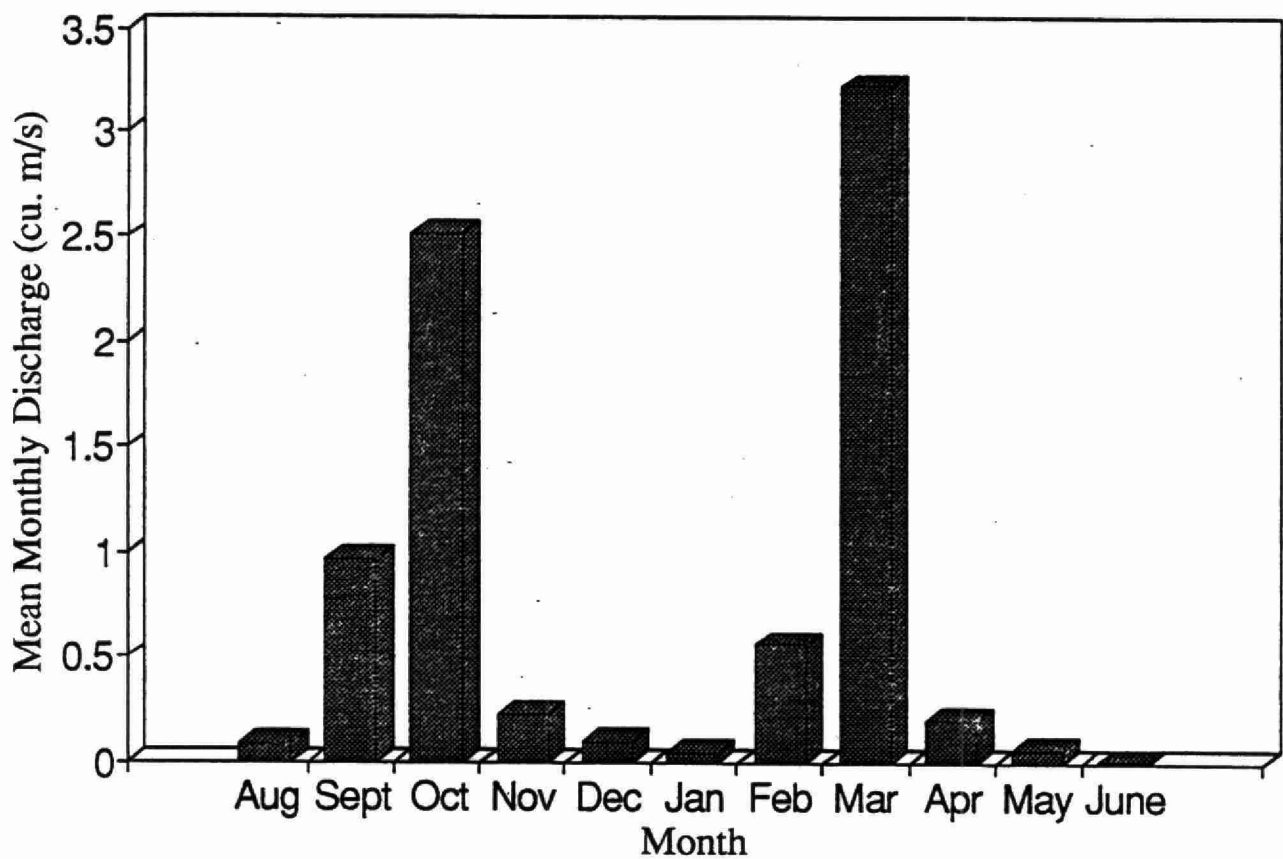
—■— Big Carp —◆— Root —*— Algoma SW-1 —□— SW5

Mean Daily Flow at Monitoring Stations
SW1 (West Davignon), SW5 (Baseline Road
Ditch), Big Carp River and Root River, 1989

Figure
5.9

December 90
Rev. 00

SW1 For 1988-89

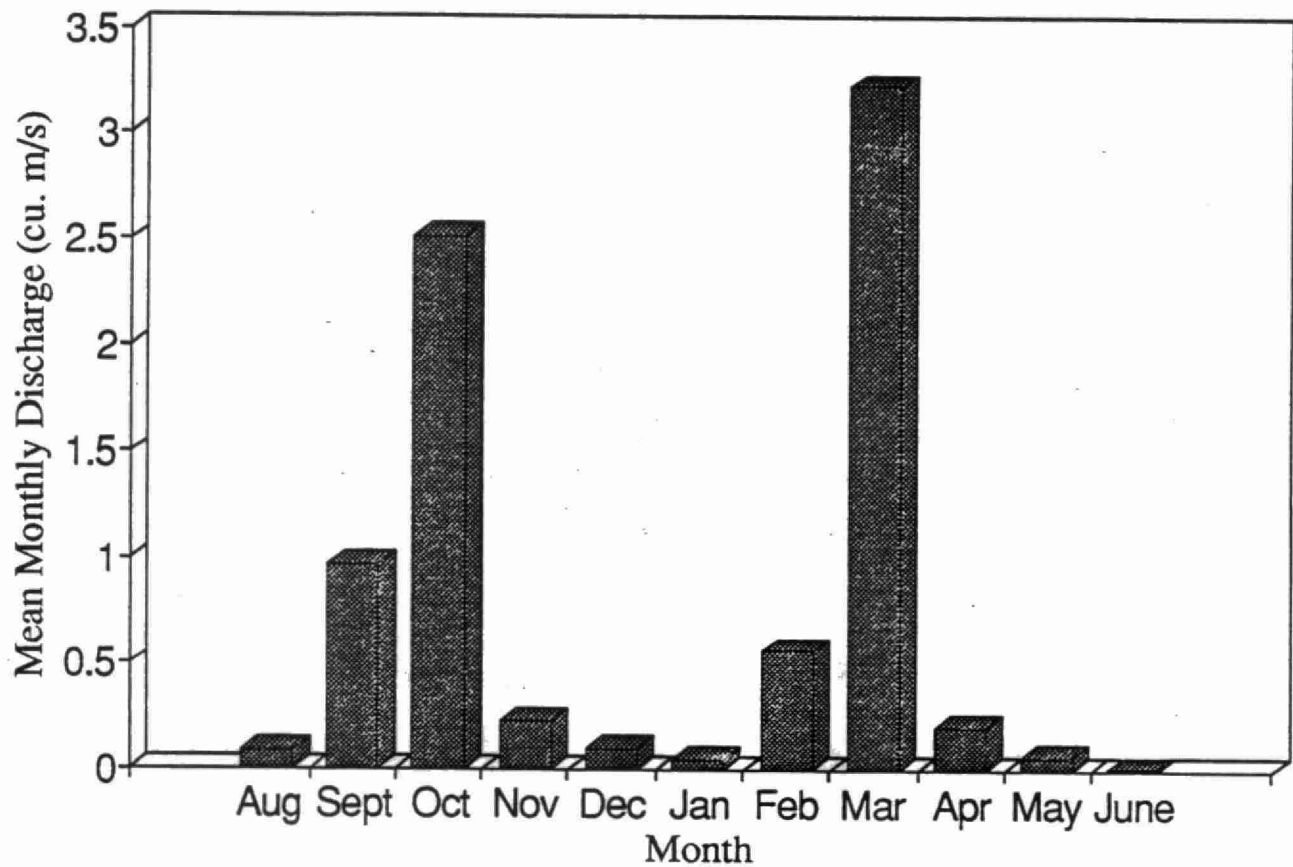


**Mean Monthly Flow at Monitoring Station
SW1 (West Davignon), 1988-1989**

Figure
5.10

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Rev. 00

SW2
For 1988-89

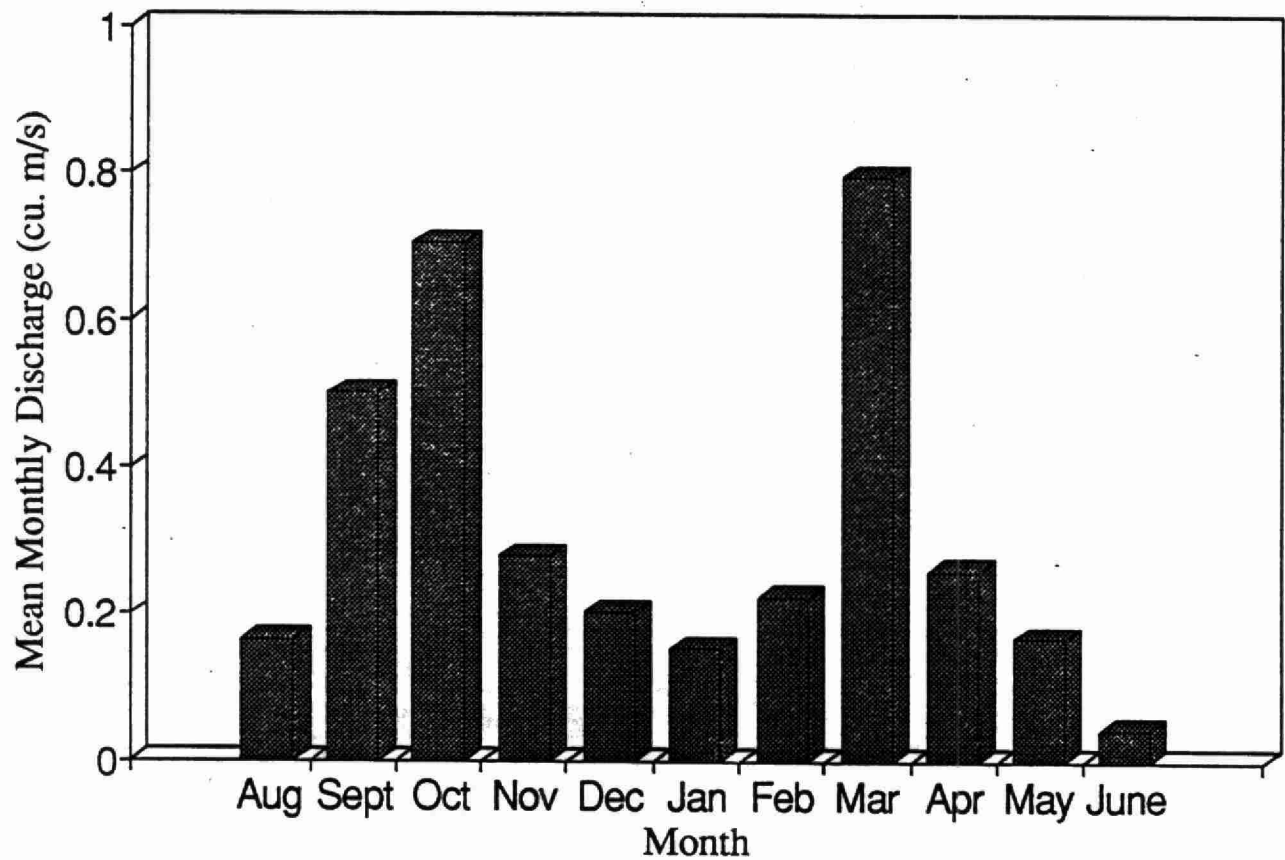


Mean Monthly Flow at Monitoring Station
SW2 (West Davignon), 1988-1989

Figure
5.11

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Rev. 00

SW3
For 1988-89

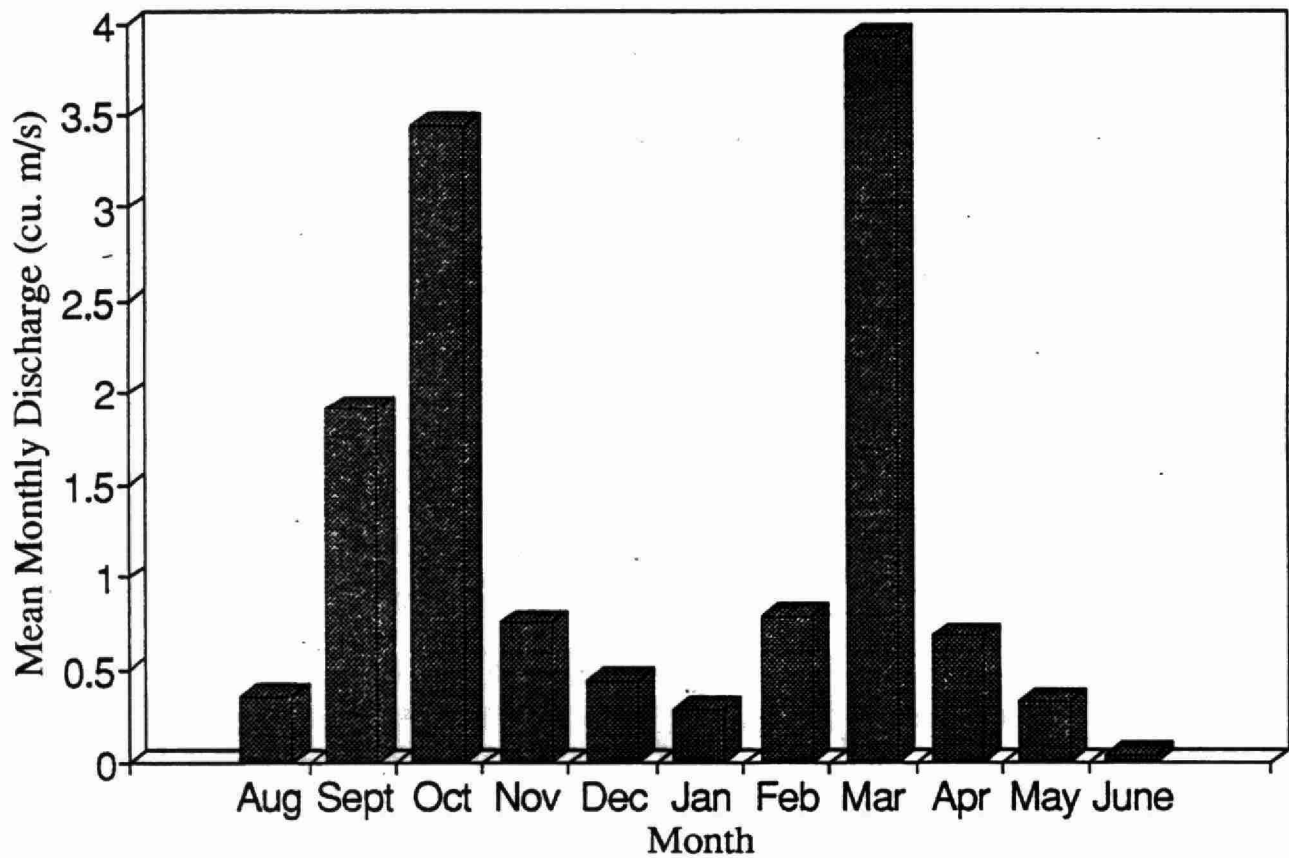


Mean Monthly Flow at Monitoring Station
SW3 (Bennett Creek), 1988-1989

Figure
5.12

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Rev. 00

Big Carp River For 1988-89



**Mean Monthly Flow at Monitoring Station
Big Carp River, 1988-1989**

Figure
5.13

December 90
Rev. 00

APPENDIX 1

**FIELD PROTOCOLS FOR THE
HYDROGEOLOGIC STUDY**

PROTOCOL NO. 1

**SUPERVISION OF EXPLORATORY
BOREHOLES FOR MONITORING WELLS**

PROTOCOL NO. 1
SUPERVISION OF EXPLORATORY
BOREHOLES FOR MONITORING WELLS

1.1 Introduction

This document describes the procedures that were followed during the drilling and logging of the exploratory boreholes at the Algoma slag site in Sault Ste. Marie, Ontario. Exploratory boreholes were drilled at each location where a monitoring well was scheduled to be installed. Monitoring wells designed to indicate the potentiometric surface and water quality of a particular hydrostratigraphic zone were installed in each of the exploratory boreholes. At several locations, an additional monitoring well was installed in a shallower borehole drilled within 2 to 3 m (laterally) of the original, deep borehole to create a nest of monitoring wells.

1.2 Drilling

Exploratory boreholes for the monitoring wells were drilled using one of the following methods depending on the subsurface geologic conditions.

- hollow stem augers in unconsolidated natural geologic materials; or
- tri-cone water rotary in bedrock materials.

A Terraqua or BEAK hydrogeologist or geotechnical engineer attended the drillers continually to specify the borehole location, drilling method, rate of drill penetration, depth of sample collection, method of sample retrieval and total depth of the borehole.

1.2.1 Hollow Stem Augers

Exploratory boreholes terminated in the unconsolidated materials were drilled using a CME-75 drill rig equipped with hollow stem augers. The 10.8 cm (4 1/4") inside diameter of the augers was sufficiently large to contain the 5 cm (2") O.D. well that was constructed in each borehole. Continuous samples of the geologic materials were collected from selected boreholes using a 10.8 cm (4 1/4") outside diameter CME continuous sampler. The continuous sampler was positioned inside the annulus of the lead auger (the auger with the bit attached) with its cutting edge extending approximately 10 cm out in front of (ahead of) the bit. As the augers slowly twist into the ground, the continuous sampler collected a 1.5 m long undisturbed core of the geologic materials encountered by the lead auger. The continuous corer was removed from the borehole, emptied onto a sheet of clean plastic, brushed clean with a wire brush, reassembled, and repositioned at the front of the lead auger. A spring steel catchment prevents the solid sample from sliding out of the sampler and falling into the annulus of the augers. This method was only possible in the clay and silt found below the slag, as it was often ineffective in penetrating and/or retrieving samples of the coarse stoney slag or granular overburden.

As a result of the varied and sometimes difficult drilling conditions encountered across the site, split-spoon sampling was employed at most drilling locations. Generally, 0.45 to 0.75 metre samples were collected every 1.5 metres, but this sampling interval varied depending on the type and extent of geologic units encountered. Samples were collected by driving the smaller split-spoon sampler (3.8 cm I.D. x 45.7 cm long) into the undisturbed geologic materials ahead of the drill bit. When geologic samples were not collected during drilling, a solid plug was positioned at the front of the lead auger, just behind the bit, to prevent the migration of materials up the annulus of the drill string.

1.2.2 Other Drilling Methods

Water-rotary drilling, using a 25 cm (10") diameter carbide-tip tri-cone bit, was used at deep boreholes (A7-1 and B2-3) that penetrated bedrock. Water from the municipal supply was circulated in order to bring cuttings to the surface and to keep the walls of the hole from collapsing. Cuttings were collected using a sieve at 1.5 to 3 metre intervals during borehole advancement.

At boreholes B2-1 and B2-3, larger diameter (10-inch LD.) augers or drill bits were used to drill through 3 to 4 metres of stockpiled coal at ground surface. Large diameter casing was driven down to the underlying clay and was sealed in place with bentonite cement grout as a precautionary measure to prevent any potentially contaminated surface materials from being carried down the borehole during drilling activities. Following partial setting of the grout, smaller diameter augers (or drill bit) were used to drill through the grout and penetrate the native geologic material below the coal.

1.3 Cleaning of Equipment

No drilling fluids or additives were used during the drilling of the exploratory boreholes with the hollow stem augers. Additionally, no greases, solvents or organic or inorganic compounds of any type were used during any of the drilling procedures. The drilling rig, drill rods, augers, temporary casings, samplers and all other equipment that came in contact with the borehole or the well materials were pressure-washed before the drilling of each exploratory borehole at each location. Only clean water from the municipal supply was used to mix drilling fluids and to decontaminate the equipment.

1.4 Sample Logging

All samples collected using the above methods were photographed and geologically logged in the field. Representative subsamples were placed in labelled clean glass jars for future reference, and the subsample numbers were recorded in the project field books. Detailed borehole logs containing geologic descriptions have been constructed for each of the exploratory boreholes. The borehole logs contain observations noted during the drilling procedure, the locations from which sub-samples were collected, and the details of the construction of the well.

PROTOCOL NO. 2

SOIL SAMPLING

PROTOCOL NO. 2

SOIL SAMPLING

2.1 Introduction

This document describes the procedures followed during sampling of subsurface soils at the Algoma slag site in Sault Ste. Marie, Ontario. Soil samples were collected from each of the exploratory boreholes for geologic logging and leach testing analysis.

2.2 Sampling

2.2.1 Sample Collection

Individual soil samples were collected from continuous geologic cores or split-spoon samples obtained during the drilling of the exploratory boreholes following the procedures outlined in Protocol 1. The samples were subsampled to obtain a representative suite of soil samples for analysis.

Subsamples were obtained using stainless steel spatulas. The outside portion of a larger piece of the continuous core were trimmed until a small sub-core remained. Care was taken to handle or disturb this sub-core as little as possible when transferring it to the sample container.

The following information was recorded in the field book at the time of sample collection.

- sample number,
- date and time sampled,
- borehole number, and
- depth.

2.2.2 Sample Containers

Sample bottles were cleaned by the analytical laboratory using standard approved protocols. The sample bottles and caps were protected from contamination between the time of receipt by BEAK personnel and usage at the sampling site. The soil samples were stored in glass sample containers. The specifications of the sample containers used for the soils are summarized in Table P6.1. Sample containers were labelled with self-adhesive tags on which the following information was inscribed in waterproof ink:

- project number,
- project name,
- sample number, and
- sample date.

2.2.3 Storage and Transportation

Care was taken to limit the exposure of the samples to dust, direct sunlight, and adverse weather conditions. Once sealed and labelled, all the samples were placed in cooler chests with ice for the remainder of the day at the site. At the end of the working day, all samples were transferred to a refrigerator where they remained until they were shipped to the laboratory for analysis. Samples were shipped to the laboratory within three days of their collection at the site.

2.3 Equipment Decontamination

Equipment used to prepare the subsamples was wiped clean between samples using clean paper towels.

PROTOCOL NO. 3

INSTALLATION OF MONITORING WELLS

PROTOCOL NO. 3

INSTALLATION OF MONITORING WELLS

3.1 Introduction

This document describes the procedures to be followed during the installation of the monitoring wells in the boreholes at the Algoma slag site in Sault Ste. Marie, Ontario.

A single monitoring well was installed in each exploratory borehole. Additional monitoring wells were constructed in shallower boreholes drilled within 2 to 3 m of some of the deeper exploratory boreholes. The well nests formed by the pairs of deep and shallow monitoring wells positioned in separate boreholes drilled at roughly the same location specifically provide information concerning the nature of vertical hydraulic gradients at each nest location and allow sampling of the deep and shallow zones.

3.2 Monitoring well Installation

3.2.1 Introduction

Each monitoring well was designed to display the potentiometric surface and permit the collection of groundwater samples from the geologic materials in which the sand pack was positioned. Well screen intervals were selected based on observation of the samples collected from each of the boreholes and the location of the watertable. Drilling of the borehole, and collection and logging of the geologic samples, was performed in accordance with Protocols 1 and 2. Construction of the monitoring wells within the borehole followed the procedures outlined in the following sections.

3.2.2 Screen and Riser Pipe

Most of the monitoring wells were constructed from Schedule 40 polyvinyl chloride (PVC) casing. The inside diameter of the casing is sufficiently large to permit the entry of water level measuring and water sampling devices. The well screens consist of PVC casing which is factory slotted (slot width = 0.01") to permit the entry of water into the well. The bottom of the screens were plugged with the appropriately-sized screw-in cap. The appropriate number of 5-foot screen sections and 10-foot risers were coupled via threaded joints to construct the well. Shorter sections of screen were incorporated into the deep monitors of some of the nested installations, and longer sections were installed in very fine-grained materials (i.e., clay). Suitably-sized O-rings were placed between the sections of the PVC monitoring wells to prevent the entry of water into the well through the threads of the joint. No PVC cements or other solvents were used in the construction of the wells.

3.2.3 Filter Material

Clean, coarse silica sand was positioned around the well screen to transmit water from the surrounding geologic materials into the well.

3.2.4 Setting Screens, Riser Casings and Filter Materials

Upon completion of boreholes drilled with hollow stem augers, the necessary well materials were assembled and lowered down the inside of the augers to the bottom of the borehole. Wells installed in boreholes drilled using tri-cone mud rotary were constructed inside the temporary surface casing placed in the borehole during drilling to prevent the collapse of the borehole upon removal of the drilling assembly. The plugged bottom of the well screen was positioned flush with the bottom of the borehole and sufficient lengths of riser were added to ensure that approximately 1 m of the riser did protrude above the ground surface.

After the monitoring well assembly had been lowered to the bottom of the borehole, silica sand was added via the inside of the augers or casing to fill the annular space created between the outside of the PVC well materials and the inside of the borehole during the slow withdrawal of the augers/casing. The top of the sand in the borehole was constantly plumbed with a weighted measuring tape as the sand was poured to ensure that the filter material was passing through the annulus of the augers without obstruction and flowing evenly into the open borehole around the well screen. Silica sand was added until the level of the sand in the borehole was approximately 0.6 m above the top of the screened interval.

3.2.5 Setting Seals and Grouting

Once the depth to the top of the filter pack was verified to be in the correct position, a 0.6 to 1 m layer of bentonite pellets was placed on top of the sand pack to seal the screened interval of the well off from the overlying fluids/geologic materials. The depth to the top of the bentonite seal was verified using a weighted measuring tape. Seals which were below the watertable were naturally moistened by inflowing groundwater. Where a seal was placed above the watertable, a layer of fine-grained bentonite (benseal) was poured on top of the pellets, and 4 litres of distilled water were added to ensure quick expansion of the seal. This water interacted with the pellets, causing them to begin to swell and thereby immediately sealing off the well screen/sand pack from any fluids migrating downward from above.

The bentonite seal thicknesses ranged from 0.6 to 1.0 metres (2 to 3 feet) in single monitoring wells which were screened in native unconsolidated material. The seals were generally 0.3 metres (1 foot) thick in boreholes that were installed in slag material. The reason being that the slag tended to be very coarse and susceptible to surface water infiltration; hence an extensive seal was not necessary.

The integrity of seals installed above the sand packs of deep monitors which were part of nested installations were of particular concern. In such cases, the bentonite pellet seals were

supplemented with a bentonite cement mixture which was injected into the borehole annulus via a tremmie pipe, up to at least the elevation of the base of the shallow nested well. Bentonite cement was also used to seal some of the shallow installations, and to seal any clayey or silty units that may have been penetrated during drilling.

At well A7-1, a 6-inch steel casing was seated into bedrock and the well was deepened until a water-bearing unit was encountered. The annular space between the casing and the native overburden was sealed using bentonite cement, which extended a significant distance into the overburden to prevent the migration of surface water down the casing.

Following the construction of the seals at the appropriate intervals, the augers were removed and the overburden was allowed to collapse around the PVC casing to within a few feet of ground surface.

3.2.6 Protective Casings

The tops of all wells except A7-1 were capped to prevent the entry of foreign material using a friction-fit or threaded PVC cap placed on the top of each monitoring well, and a lockable protective steel casing was installed over the well casing top. The steel casings were sealed at ground surface with Portland cement in order to prevent the entry and migration of surface water down the borehole. At A7-1, a steel cap with a threaded port (for monitoring and sampling purposes) was welded onto the top of the 6-inch steel well casing.

3.2.7 Documentation of the Monitoring Well Configuration

Scaled diagrams of the wells constructed in each of the boreholes are included in Appendix 2.

3.3 Cleaning of Equipment

The PVC casing and screen materials for the monitoring wells were factory cleaned and individually sealed in plastic sleeves prior to shipment to the site. Immediately prior the construction of the well, all the PVC well materials were removed from their plastic coverings, and were handled only by persons wearing clean latex gloves.

PROTOCOL NO. 4

DEVELOPMENT OF MONITORING WELLS

PROTOCOL NO. 4
DEVELOPMENT OF MONITORING WELLS

4.1 Introduction

This document describes the procedures used during monitoring well development at the Algoma slag site in Sault Ste. Marie, Ontario.

4.2 Development of Monitoring wells

After the monitoring well installation was completed and the wells had been allowed to set for at least 48 hours, they were developed by pumping to remove as much silt as possible from the well to enhance the performance of the well screen/sand pack. Each well, except A7-1 and B2-3, was developed using dedicated Waterra pumps that were stored in the well bore. The pH, specific conductance, temperature and total volume of water pumped was monitored during well development. Well development generally proceeded until at least three bore volumes had been removed and the field water quality parameters had stabilized.

Wells A7-1 and B2-3 were pumped using a high capacity submersible pump for several minutes immediately after installation.

4.3 Waterra Pump Assembly

The Waterra pump assembly consists of a delrin foot valve attached to a length of 1.6 cm O.D. polyethylene tubing equal to the depth of the well. Oscillation of the tubing, together with the action of the foot valve, forces water to the surface. The entire pump assembly is stored in each well.

PROTOCOL NO. 5

WATER LEVEL MONITORING

PROTOCOL NO. 5

WATER LEVEL MONITORING

5.1 Introduction

This document describes the procedures that were followed during water level monitoring at the Algoma slag site in Sault Ste. Marie, Ontario.

5.2 Water Level Measurements

All water level measurements obtained after the installation of the wells were collected using an electric water level tape marked in 1 cm intervals.

The procedure used for measuring water levels is as follows:

- switch on,
- lower the weighted electric tape slowly into the well until the buzzer or light indicates a closed circuit,
- note the length of the tape which corresponds to the top of the outermost well casing,
- record the resultant value as the water level in metres below the top of the casing;
- rinse the steel-encased electrode with distilled water and wipe dry with a clean paper towel, and
- store the water level tape in a clean box.

All the water level measurements collected were recorded in the field book.

PROTOCOL NO. 6

WATER QUALITY SAMPLING

PROTOCOL NO. 6

WATER QUALITY SAMPLING

6.1 Introduction

This document describes the procedures followed during the collection of water samples from the Algoma slag site in Sault Ste. Marie, Ontario. Groundwater samples were collected from each of the monitoring wells installed at the site, with the exception of monitoring well C2-2 which was dry. Field measurements of groundwater quality were taken during pumping associated with the development of the wells and sample collection.

6.2 Approach to Sampling

6.2.1 Introduction

Concentrations of pollutants in contaminated waters may range from ng/L (e.g., mercury at 50 ng/g) to several hundred µg/L. Because of the very low concentrations, and the variability of these concentrations, extreme care is required during sampling to ensure that representative, uncontaminated, and properly preserved samples are collected.

This section presents a review of the special requirements necessary to obtain appropriate samples. Subsequent sections present detailed procedures that will ensure these requirements are met.

6.2.2 Potential for Contamination

There is a risk of contamination in every step of sample collection, preservation, shipping and handling of samples. Consequently, special samplers, special sampler materials, and careful sample handling are required. Some of the potential sources of contamination include:

- improperly cleaned sample containers, funnels, graduated cylinders, etc., especially for extractable organics, and metals,
- poor bottle handling (e.g., fingerprints inside bottles),
- dusty or dirty conditions where samples are being collected or sub-divided (especially for metals), and
- improper sampling equipment.

All of the materials and procedures described in this protocol have been selected to minimize the potential for contamination. Glass (either flint or pyrex) is the best for either organic sampling or handling. If inorganics are being sampled, then hard polyethylene is appropriate.

The bottles were stored in a box away from dust. The mouths of the bottles were not allowed to come in contact with other materials when in use.

6.3 Groundwater Sample Collection

Samples were collected from each of the monitoring wells using the following procedures:

- Sampling of the wells was initiated after the majority of the wells had recovered after well development.
- A minimum of three casing volumes of water was removed from each well before the samples were collected. Wells which yielded less than three casing volumes of water during a single pumping event were pumped on successive days until the minimum three volumes had been removed. A minimum of one casing volume was removed immediately prior to sampling. Periodic measurements of temperature, pH and specific conductance were made during pumping to ensure that these parameters were stable and that the water samples were therefore representative of the aquifer.

- A Waterra pumping system was dedicated to each monitoring well except A7-1. A bottom loading/bottom emptying translucent teflon bailer was used to collect samples from monitoring well A7-1.
- Sample containers were filled, appropriate preservative added and the cap replaced immediately. Samples to be analysed for volatile organic compounds (VOCs) were carefully collected to minimize agitation and to ensure that no headspace was present in the sample container.
- The samples to be analyzed for metals were filtered (0.45 μm membrane) in the field using a suction-powered Sartorius tower filtration unit or in-line Sample Pro filters to remove unwanted suspended sediment.
- The following information was recorded in the field book
 - sample name,
 - date and time sampled,
 - water level before pumping,
 - volume of water removed prior to collection of sample,
 - results of periodic field measurements (pH, specific conductance, temperature),
 - general observations of the water, and
 - final water level after collection of the sample.

6.4 Mini-Piezometer Sampling

Sampling of mini-piezometers was conducted in a manner similar to the full-size monitoring wells. Two litres of water were removed from each mini-piezometers, using a 1 L vacuum flask and hand pump, prior to sample collection. Measurements of pH, temperature and specific conductance were made after each litre was removed. The flask was then emptied and filled via pumping. Sample containers were filled by pouring water from the flask and the appropriate preservative was added. Samples for metals analyses were filtered in the field using a suction-powered Sartorius filtration unit and 0.45 μm filters. The following information was recorded in the field book:

- sample name,
- date and time sampled,
- volume of water removed prior to sample collection,
- results of field measurements, and
- general observations of the water.

6.5 Sample Labelling

All sample containers were labelled with self-adhesive tags bearing the following information inscribed in waterproof ink:

- project number,
- project name,
- sample number,
- date and time samples were obtained,
- treatment (preservatives, filtration etc.),
- analysis to be performed.

6.6 Sample Containers and Volumes

The sample containers were either glass or plastic and were obtained from the laboratory. A list of the sample containers used is given in Table P6.1.

6.7 Sample Preservation and Storage

A list of the analytical parameters and sample preservatives for the water samples from the Algoma slag site, is presented in Table P6.1.

6.8 Quality Control Samples

Several field procedures were employed to document the effectiveness of the sampling techniques and the precision and accuracy of the analytical data generated by the laboratory.

Duplicate samples were collected from approximately 5% of the wells. These samples were collected within two to five minutes of the original samples. Field trip blanks consisting of sample containers filled with deionized water in the laboratory comprised 5% of the samples. These were opened on-site, the appropriate preservatives added and recapped. The trip blanks were stored and shipped with the regular samples.

6.9 Storage, Shipping and Receipt of Samples

Care was taken to limit the exposure of the samples to dust, direct sunlight and adverse weather conditions. Once sealed and labelled, all samples were placed in cooler chests for the remainder of the day at the site. At the end of the working day, all samples were transferred to a refrigerator where they remained until they were shipped to the laboratory for analysis. Samples were shipped by overnight air courier to the laboratory within three working days of their collection.

6.10 Field Measurements

Field pH, specific conductance and temperature measurements were performed on the water samples. All data was recorded in the field book. The following procedures were used to perform the field water quality measurements.

6.10.1 Temperature

Temperature was measured using a mercury-filled thermometer. Approximately three field measurements of the temperature of the water were taken for each episode of pumping.

6.10.2 pH

Approximately three determinations of pH were obtained at sampling location. The pH measurement recorded for each groundwater sample corresponds to that obtained for the final litre of water pumped from the well immediately prior to the collection of the groundwater samples.

The physical condition of the pH electrode and meter was checked at the beginning and end of each day. Calibration and measurement procedures were performed in accordance with the manufacturers specifications as outlined in the instruction manual for the meter. Buffers which have been cooled to the temperature of the groundwater (approximately 10°C) were used to calibrate the meter at the beginning, end and periodically throughout the day. The electrode was rinsed with distilled water before and after each measurement. It was then agitated in the sample and allowed to soak for a further couple of minutes before a reading was obtained.

6.10.3 Specific Conductance

Specific conductance measurements were performed simultaneous with pH measurements on the same groundwater water sample. Specific conductance determinations were, therefore, collected on the same schedule as the pH determinations as outlined above.

The physical condition of the meter and probe was checked periodically to ensure that it was in good working condition. The conductivity meter was calibrated at the beginning and end

of each day using a standard solution with a known specific conductance as outlined in the instruction manual for the meter.

The specific conductance was measured after the probe had been stirred, and then allowed to sit in the sample for one to two minutes. Specific conductance measurements were recorded and reported in units of microsiemens per centimeter ($\mu\text{S}/\text{cm}$) at 25°C . The sample used for field measurements was then discarded and not subjected to any further testing.

6.10.4 Dissolved Oxygen

During the first round of groundwater samples, the dissolved oxygen content of the water sample was measured using an electrode. A water sample was collected, used immediately for determination of dissolved oxygen, and then discarded. The probe was not lowered down the well. Dissolved oxygen was determined by winkler titrations conducted nightly on preserved samples for subsequent rounds of sampling.

6.11 Documentation

6.11.1 Field Book

A field book containing all the information collected during the sampling operations, as described above, was maintained.

6.11.2 Chain of Custody Procedures

After the samples are collected and labelled, they were maintained under the chain of custody procedures outlined below. These procedures and forms document the transfer of custody of the samples from the field personnel to the designated laboratory.

Chain of custody records are completed for each shipment of samples sent to the laboratory. The information recorded on the form includes:

- name of project and sampler,
- sample number and location,
- date and time sample was taken,
- type of sample,
- number of bottles per sample, and
- remarks regarding sample.

The samples are then packed in ice in cooler chests, the original chain of custody records enclosed, and shipped to the laboratory.

6.12 Cleaning of Equipment

Sample bottles and bottle caps were cleaned by the analytical laboratory using standard approved protocols. Sample bottles and caps were protected from contamination between the time of receipt by BEAK and the time of usage at the site.

The Waterra pumps used to develop the wells were factory cleaned and dedicated to each of the wells following the procedure outlined in Protocol 4.

The teflon bailer that was used to collect samples from monitoring well A7-1 was cleaned before use and after sampling was completed using the following procedure:

- rinse inside and out with tap water,
- rinse inside and out two times with hexane solvent,
- air dry,
- rinse inside and out with tap water,

- rinse inside and out with distilled water, and
- air dry.

Thermometers, electrodes and conductivity probes were cleaned repeatedly at each well, and between wells, by rinsing with distilled water and wiping with a clean paper towel.

TABLE P6.1: SAMPLE HANDLING REQUIREMENTS

No.	Bottle Type	Analytical Parameter	Preservative
Level No. 1*			
1	500 mL polyethylene	wet chemistry	-
1	250 mL polyethylene	metals	nitric acid
1	250 mL amber glass	oil and grease	sulphuric acid
1	250 mL amber glass	phenol	copper sulphate
Level No. 2*			
1	500 mL polyethylene	wet chemistry	-
1	250 mL amber glass	phenol	copper sulphate
1	250 mL polyethylene	metals	nitric acid
1	100 mL amber glass	sulphide	zinc acetate
1	1,000 mL amber glass	PAH	-
1	100 mL glass with teflon septum cap	VOC	sodium thiosulphate
Level No. 3*			
1	500 mL polyethylene	wet chemistry	-
1	250 mL amber glass	phenol	copper sulphate
1	250 mL polyethylene	metals	nitric acid
1	100 mL glass with teflon septum cap	VOC	sodium thiosulphate
1	1,000 mL amber glass	PAH	-
1	250 mL amber glass	PCB	-
1	500 mL polyethylene	cyanide	sodium hydroxide
1	100 mL amber glass	sulphide	zinc acetate
1	100 mL amber glass	mercury	dichromate
1	1,000 mL amber glass	phenol species	-

* Levels are for first sampling round only. Bottle types and preservatives are same for subsequent sampling rounds but occur in different levels.

PROTOCOL NO. 7

RESPONSE TESTS

PROTOCOL NO. 7

RESPONSE TESTS

7.1 Introduction

This document describes the procedures followed during the performance of response tests on selected monitoring wells installed at the Algoma slag site in Sault Ste. Marie, Ontario. Response tests were conducted at all monitoring wells except A7-1 (which was not tested as its relatively large diameter made this impractical), and B2-3 (which was installed after conclusion of the response tests). To perform the tests, the water level in each well was rapidly lowered as much as possible and then observed as it recovered toward equilibrium. The rate at which the water level in the well recovers is a function of the bulk (average) hydraulic conductivity of the geologic materials intersected by the well screen/sand pack.

7.2 Data Collection

Response tests were performed by first measuring the static water level, and then pumping the well using the Waterra hand pump, until either the pump no longer yielded water (i.e., the well was dry), or until a maximum drawdown was achieved (i.e., the pumping rate and inflow through the screen were equivalent). Immediately after pumping was terminated, the recovery of the water level in the casing was monitored by recording the date and time, and determining the depth to water with a battery-operated water level probe attached to a calibrated measuring tape. Readings were generally taken very close together at the start of the recovery period (e.g., 15 to 30 seconds apart) and were spread out as equilibrium was approached. Monitoring continued until the water level had recovered to at least 85% of its initial level.

7.3 Interpretation

The recovery data were interpreted via the method of Hvorslev (1951) to determine the average saturated hydraulic conductivity of the geologic materials which surround the well screens. Interpretation of the field recovery data initiated by plotting the log of the relative recovery $(H-h/H-h_0)$; where H = equilibrium water level, h = current water level data point during recovery and h_0 = water level at maximum drawdown immediately after pumping vs. time elapsed since the end of the pumping). The basic time lag of each well, T_0 , is measured graphically off each recovery plot (time corresponding to when $H-h/H-H_0 = 0.37$ or $\ln(H-h/H-H_0) = -1$) and used in the following formula to calculate K , the hydraulic conductivity of the geologic materials surrounding the well screen/sand pack.

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

where: K = hydraulic conductivity (ft/hr)
 r = radius of casing (ft)
 L = length of sand pack (ft)
 R = radius of sand pack/well screen (ft)
 T_0 = basic time lag (hrs)

This simple interpretation of the field recovery data assumes a homogeneous isotropic infinite geologic medium in which the soil and water are incompressible.

Several test results obtained for this study are characterized by two distinct response periods: an initial rapid water level recovery characterized by a steep line on the dimensionless response versus time plot and a later slower recovery characterized by a less steep line. This behaviour generally occurred when the water level in the well was lowered significantly below the top of the sand pack, thereby dewatering the sand pack. The initial rapid water level

recovery represents resaturation of the sand pack and is not representative of the response of the geologic materials intersected by the sand pack. The test start time (T_0) was adjusted to the time at which the later slower recovery was observed to begin to calculate a more representative hydraulic conductivity value for the geologic materials.

APPENDIX 2

Borehole Logs and Well Development Data

BOREHOLE LOGS

[illegible]

BOREHOLE NO. A1-1 and A1-2

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 14, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 192.4 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO.	T Y P E	
0	SLAG			
	grey coarse sand to fine gravel size slag, iron stain, gypsum, damp		SS ↓	
10	as above	A1-9.5	SS ↓	
	med. brown sand, grey brown and black slag, slight oily odour, no visible oil	A1-15	SS ↓	
20	slag, saturated, oily film/odour on water	A1-19.5	SS ↓	
	white to grey gypsum, oily stains, damp	A1-21.5	↓	
	pink/brown SAND and SILTY FINE SAND, iron stain, strong oily odour	A1-25	SS ↓	
	brown sand, black stain and oily odour	A1-26	↓	
30	med. to fine brown sand, saturated, strong oily odour, no visible		SS ↓	
		A1-31	↓	
	red SILTY MED. to COARSE sand, red black sandstone semi-rounded pebbles	A1-35	SS ↓	
40	as above, siltier with slight oily odour		↓	
	saturated red silty sand, black pebbles	A1-41.5	SS ↓	
	saturated semi angular gravel (red sand- stone, white quartz and black clasts) some fine to med. sandy pockets	A1-45	SS ↓	
50	saturated med. SILTY SAND, pink/brown, slightly cohesive	A1-50	SS ↓	

BOREHOLE NO. A1-1 and A1-2 continued

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 14, 1988

BOREHOLE TYPE Hollow Stem
Auger

APPROX. GROUND SURFACE
ELEVATION 192.4 m.

[illegible]

BOREHOLE NO. A2-1 and A2-2

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE July 26, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 192.7 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	TYPE	
0	SLAG blue/grey/yellow, med. to fine sand and gravel sized. Up to 13 cm cobbles at top, finer at base.	A2-4	SS	
10			SS	
			SS	
			SS	
20	reddish orange/brown SAND, some silt, red gravel and rock fragments	A2-19	SS	
		A2-20 A2-21		
	saturated (soupy), silty sand and gravel, red/brown		SS	
30		A2-29	SS	
	- as above, coarser sand			
	- as above, with 5 cm stones		SS	
	stiff, red medium SAND and ROCK FRAGMENTS (red sandstone), moist	A2-37	SS	
40				
	- weathered and broken red SANDSTONE, stiff and dense		SS	
50				
				BOREHOLE TERMINATED

BOREHOLE NO. A3

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 5, 1988

BOREHOLE TYPE Hollow Stem
Auger

APPROX. GROUND SURFACE
ELEVATION 185.65 m.

[illegible]

BOREHOLE NO. A4-1 and A4-2

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 5, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 185.35 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	TYPE	
				A4-2 A4-1
0	SLAG			
	Gravel size slag, brown silt, very moist	A4-5	CTS	
	Greenish grey, very FINE SANDY SILT, damp	A4-10		
10	SAND and GRAVEL, saturated			
20	- layered CLAY and SILT : 1 cm red clay layers, 0.5 cm brown silt layers; very cohesive, near saturation	A4-20		
	- as above, very moist		SS	
		A4-25	SS	
30	- red clay, (1 cm layers), brown silt (0.5 to 1 cm layers)			
	- red clay, very cohesive, very moist		SS	
	- red clay, very moist		SS	
40	- layered silt and silty clay; very soft, cohesive, near saturation			
	brown silt 1 to 2 cm layers, red/brown silty clay 0.25 to 0.5 cm layers	A4-40	SS	
	- laminated red silty clay and brown silt			
	- layered brown silt with fine sand partings, free water in sand	A4-46	SS	
50	coarse SAND to fine GRAVEL (semi-rounded red sandstone, quartz and black clasts), saturated, trace silt	A4-50	SS	

[illegible]

BOREHOLE NO. A5

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 4, 1988

BOREHOLE TYPE Hollow Stem

APPROX. GROUND SURFACE

Auger

ELEVATION 187.0 m.

[illegible]

BOREHOLE NO. A6

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 4, 1988

BOREHOLE TYPE Hollow Stem
Auger

APPROX. GROUND SURFACE
ELEVATION 187.1 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUN WATER MONITORS
		NO	TYPE	
0	SLAG			
	Silty sand, dark brown/black, gravel size slag, saturated		SS	
10	SAND, some gravel, trace silt, brown, clayey seams	A6-11	SS	
	Silty sand, dark brown, rootlets, pebbles, saturated			
	Red brown CLAY, SILT, SILTY SAND	A6-16	SS	
	-brown silty clay			

BOREHOLE NO. A7-1

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 16, 1988

BOREHOLE TYPE Wet Rotary

APPROX. GROUND SURFACE
ELEVATION 186.9 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	TYPE	
0	FILL			
	Medium sand, saturated			
	silty sand and gravel fill			
	Pink/Brown CLAYEY SILT			
10	Red/brown clay, very cohesive, sticky, moist, soft			
20	- siltier			
	-brown silt, clay mottles			
	-layered red clay (2 cm layers) and red/brown silty clay (0.5 cm layers) soft, moist			
30	-layered red clay (0.5 - 1 cm layers) and brown silt (0.5 cm layers), soft, moist			
	-clayey silt, saturated, 0.25 cm clay layers			
40	-red silty clay (1-2cm layers) and brown silt (0.5cm layers)			
50	-red clay and brown silt, layered		Sieve	

BOREHOLE NO. A7-1 CONTINUED

PROJECT TA8873 ALGOMA STEEL

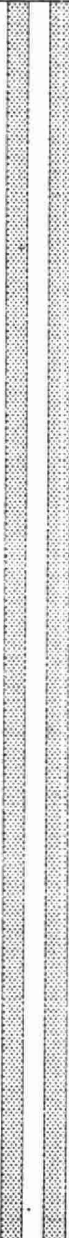
GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 16, 1988

BOREHOLE TYPE Wet Rotary

APPROX. GROUND SURFACE
ELEVATION 186.9 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		N O	T Y P E	
				Continued
50				
	Red CLAY, some brown SILT, layered		Sieve	
60	-as above		Sieve	
70	-as above		Sieve	
80	-silt and clay, layered		Sieve	
90	-saturated FINE SAND		Sieve	
100	med. to coarse SAND and GRAVEL, brown		Sieve	

BOREHOLE NO. A7-1 CONTINUED

PROJECT TA8873 ALGOMA STEEL

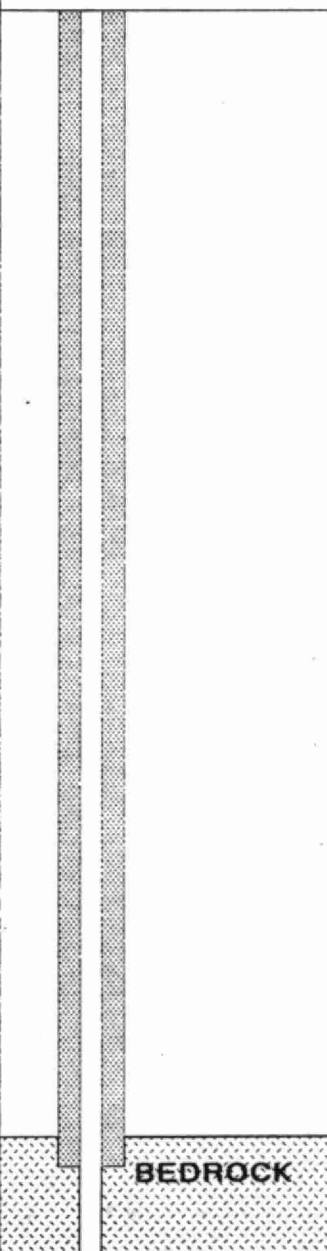
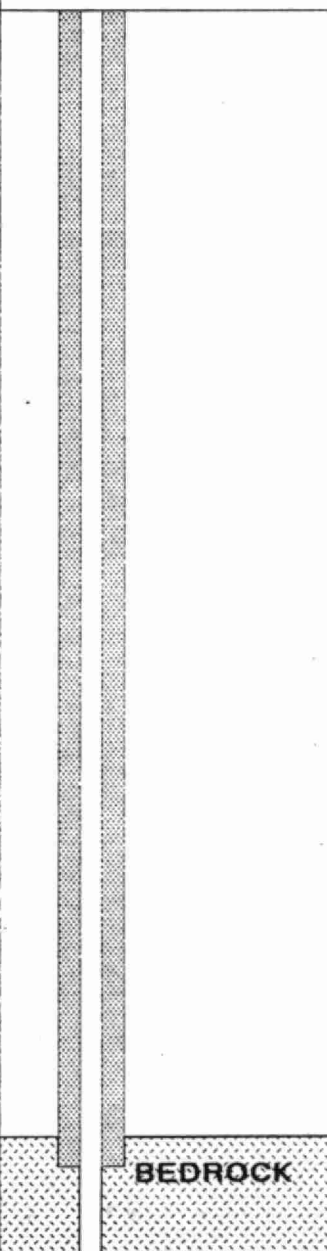
GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 16, 1988

BOREHOLE TYPE Wet Rotary

APPROX. GROUND SURFACE
ELEVATION 186.9 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		N O	T Y P E	
				Continued
100				
	med. to coarse SAND and GRAVEL, brown		Sieve	
110	fine to med. sand with pebbles, trace silt		Sieve	
120	COARSE SAND -red, black, green and white		Sieve	
130	coarse sand and gravel- red, black, green, grey, white		Sieve	
140	-as above, coarse sand, lost circulation		Sieve	
	-red, black, green and white gravel		Sieve	
150	Red and white SANDSTONE Water found at 149'			

APPROX. GROUND SURFACE
ELEVATION 186.9 m.

[illegible]

BOREHOLE NO. A7-2


PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 9, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 186.9 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	TYPE	
0	FILL			 <p>clay auger cuttings</p>
	Medium sand, saturated			
	-silty sand and gravel fill		SS	
	Pink/Brown CLAYEY SILT			
10	Red/brown clay, very cohesive, sticky, moist, soft		SS	
	-as above	A7-15	SS	
20	-as above, siltier towards bottom			
	-brown silt at top, clay mottles		SS	
	-layered red clay (2 cm layers) and red/brown silty clay (0.5 cm layers) soft, moist		SS	
30	-layered red clay (2 cm layers), and red/brown silt (0.5 cm layers), soft, moist	A7-30	SS	
	-as above			BOREHOLE TERMINATED
	-clayey saturated silt, 0.25 cm clay layers	A7-36	SS	
40	red silty clay (1-2cm layers) and brown silt (0.5cm layers)		SS	
50				

APPROX. GROUND SURFACE
ELEVATION 184.45 m.

[illegible]

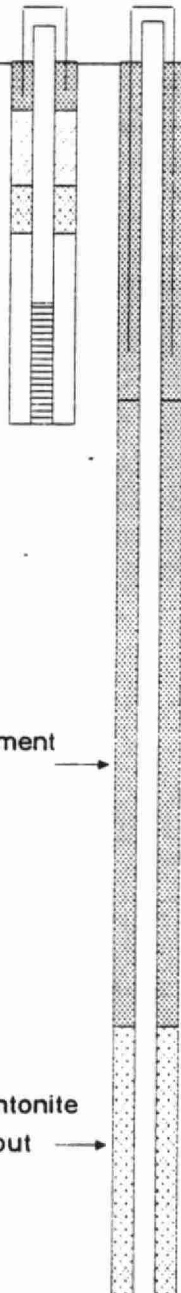
PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 13, 16, 17, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 185.5 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	TYPE	
0	COAL, dry to damp, brown/black sand to fine gravel size.			
			SS	
		B2-7	↓	
10	- as above, saturated.	B2-10		
	- pink, silty fine to med SAND, saturated	B2-11	SS ↓	
	- red clay 11' 2" to 12'; sand seam at 11' 3" with brown stain, creosote odour			
	- laminated silty fine sand, clay, silt and clayey silt, very moist, pink	B2-16	SS ↓	
	- soft pink CLAY		↓	
20	- soft, very moist, very cohesive pink/ brown clay, 1 cm silt laminae at 20' 6" and 21'		SS ↓	
	- layered SILTY CLAY (1 to 3 cm), pink/ brown and brown SILT (0.5 to 1 cm), very moist, soft	B2-25	SS ↓	
30	- as above (2 to 6 cm) clay ; silt layers (0.5 to 1 cm)		SS ↓	
	- as above (1 to 2 cm) clay ; silt layers (1 to 2 cm)	B2-35	SS ↓	
40	- as above, (0.5 cm) clay ; silt layers (0.5 cm)		SS ↓	
	- layered clay and silt	B2-45	SS ↓	
50	- as above, layered clay and silt		SS ↓	

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 13, 16, 17, 1988

BOREHOLE TYPE Hollow Stem
Auger

APPROX. GROUND SURFACE
ELEVATION 185.5 m.

[illegible]

Borehole No: B2-3

page 1 of 2

Borehole Log

Project No: 7012.3

Client: MOE

Geologist: E. Hodgins

Drilling Co.: Rennison Well Drilling

Completion Date: 19 November 1988

Location: Algoma Slag Dump

Drilling Method: Tricone/Odex

Reference Elevation: 186.23m amsl

Well Materials: 5.0cm PVC sch 40

Casing: 8in steel to 11' deep, 6in steel to 106' deep

Depth		Stratigraphy	Lithologic Description	Geologic Samples					Well Configuration	Elevations & Comments	
feet				LEL	type	recovery	location	subsamples			
										ground	185.43m
										top sand	152.61m
										bot. sand	150.03m
10			red-brown clay							sand	
										8" steel casing	
										cement	
20										6" steel casing	
30										hole plug	
40											
50											
60											
70			coarse granitic gravel (1-2cm chips)		cuttings						
			medium granitic gravel (<0.5cm chips)		cuttings						
80			coarse granitic gravel		cuttings						

[illegible]

APPROX. GROUND SURFACE
ELEVATION 184.85 m.

[illegible]

BOREHOLE NO. B4-1 and B4-2

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 10-11, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 186.05 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	T Y P E	
0				
	SLAG			
10	-Silty sand and gravel size slag, saturated, light brown and yellow/grey	B4-11	SS ↓	
	-dark grey, coarse sand size slag, some silt, sand and gravel size slag, saturated		SS ↓	
20	-as above, larger gravel component	B4-20	SS ↓	
	-med. to coarse sand, brown/black yellow and white grains (slag fragments) -dark brown silty sand and gravel size slag, some organics	B4-25	SS ↓	
30			SS ↓	
	-dark brown to black silty coarse sand and gravel size slag	B4-31	↓	
	-moist silty sandy gravel	B4-36	SS ↓	
40	Brown SILTY CLAY, SANDY, with black gravel and red sandstone clasts -red clay (1 to 3 cm layers) and brown silt (0.5 cm layers) -red clay (1 to 2 cm layers), brown silt layers (0.5 cm), very soft, very moist, and cohesive		SS ↓	
	-as above, 2 to 3 cm red clay layers, 0.5 cm brown silt layers	B4-46	SS ↓	
50	-as above, 0.5 to 1 cm layers of clay and silt -red clay		SS ↓	

BOREHOLE NO. B4-1 and B4-2 continued

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 10-11, 1988

BOREHOLE TYPE Hollow Stem Auger

APPROX. GROUND SURFACE
ELEVATION 186.05 m.

[illegible]

BOREHOLE NO. B5

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 12, 1988

BOREHOLE TYPE Hollow Stem Auger

APPROX. GROUND SURFACE
ELEVATION 185.75 m.

[illegible]

BOREHOLE NO. C1

PROJECT TA8873 ALGOMA STEEL


GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 4, 1988

BOREHOLE TYPE Hollow Stem Auger

APPROX. GROUND SURFACE
ELEVATION 192.95 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	T Y P E	
0	SLAG Coarse (2 to 5 cm) slag			
10	-as above			
	-as above		SS	
	-as above		SS	
20	-yellow brown slag, coarse sand to gravel size		SS	
	-saturated silty sand to gravel size slag, green, grey and black	C1-24		
		C1-26		
30	-layered medium to fine SAND, with interlayers of fine to med. silty sand, brown/pink			
	-saturated silty sand, pink		SS	

BOREHOLE
TERMINATED

BOREHOLE NO. C2-1 and C2-2

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB, RJB

CLIENT BEAK / MOE

DATE JULY 22, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 194.65 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	T Y P E	
0				
	SLAG silty, sandy slag, grey, blue, brown	C2- 2	CTS	
	-sand and gravel size	C2- 8		
10		C2- 10		
	-dark brown silty sand, roots, plastic, 2 to 5 cm slag, moist			
	-red/black brown silty sand, rounded gravel, moist	C2- 13	ss ▼	
	-wet red/brown silty coarse sand and rounded gravel	C2- 15	CTS ▼	
	-yellow/blue slag with dark brown soil, roots, organics			
20		C2-19.5		
	SILTY fine to medium SAND			
	STONY SANDY SILT, red/grey	C2- 23		
	Dense silty medium to fine SAND, red grey, with rock fragments			
30	BEDROCK	C2- 27		
				BOREHOLE TERMINATED
40				
50				

BOREHOLE NO. C3

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE July 26, 1988

BOREHOLE TYPE Hollow Stem Auger

APPROX. GROUND SURFACE
ELEVATION 196.3 m.

[illegible]

BOREHOLE NO. C4

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE July 26, 1988

BOREHOLE TYPE Hollow Stem
Auger

APPROX. GROUND SURFACE
ELEVATION 188.1 m.

[illegible]

BOREHOLE NO. D1-1 and D1-2

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE July 27, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 185.75 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	T Y P E	
0	SLAG Grey slag (0.5 to 3.5 cm) and dark brown med. to coarse sand			
		D1-6	SS	
10	-saturated coarse to medium sand and slag up to 5 cm, grey/blue		SS	
		D1-11		
	-as above, coated with dark brown, silty fine sand	D1-15	SS	
20	Black to brown ORGANIC SAND with blue and yellow sand size fragments	D1-19	SS	
	-saturated silty fine sand with rootlets	D1-21		
	SAND; medium reddish brown, saturated			
	-as above, a few shell fragments		SS	
30	-as above		SS	
	-as above		SS	
40	-as above		SS	
	-reddish slightly silty, medium sand with rounded black gravel		SS	
50	nearly saturated, STONY SANDY SILT		SS	
	TILL, dense, red, some clay, 3 to 4 cm stones			

BOREHOLE TERMINATED

APPROX. GROUND SURFACE
ELEVATION 185.6 m.

[illegible]

BOREHOLE NO. D3

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB, RJB

CLIENT BEAK / MOE

DATE July 29, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 184.85 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	T Y P E	
0	SLAG			D3-1 D3-2
	yellow/grey slag, black silty sand		SS ↓	
10	-saturated, coarse sand to gravel size slag, dark brown silty coating	D3-11	SS ↓	D3-1 D3-2
	-dark brown silty fine to coarse SAND and GRAVEL, saturated	D3-16	SS ↓	
20	-as above, slightly cohesive	D3-21	SS ↓	D3-1 D3-2
	-as above			
	-silty med. brown sand, some gravel	D3-25	SS ↓	D3-1 D3-2
	-brown layered CLAY and SILT, saturated, cohesive	D3-26		
30	-red/brown SILTY fine SAND, cohesive, saturated, pebbles, sandstone fragments	D3-30	SS ↓	D3-1 D3-2
	-red stony silty sand till, pebbles, near saturation, cohesive	D3-35	SS ↓	
40	-as above, near saturation			D3-1 D3-2
	-red pebbly silty sand till, dense, stiff, slightly moist, weathered red sandstone fragments	D3-40	SS ↓	
	-as above, very moist, not as stiff or dense		SS ↓	D3-1 D3-2
50	-as above, very moist at top, damp at bottom	D3-50	SS ↓	

[illegible]

BOREHOLE NO. D4

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 2, 1988

BOREHOLE TYPE Hollow Stem Auger

APPROX. GROUND SURFACE
ELEVATION 185.25 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	T Y P E	
0	SLAG			
	Black/grey slag, saturated, coarse sand to gravel size with minor silt fraction			
10	-up to 5 cm diameter slag	D4-10	ss	
	-as above, saturated, siltier	D4-16	ss	
	-black and yellow sand, white fragments, grades to fine sand	D4-18	ss	
20	-layered SILTY SAND with fine layers of sand and silty clay			
				BOREHOLE TERMINATED

BOREHOLE NO. D5-1 and D5-2

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB, RJE

CLIENT BEAK / MOE

DATE August 2, 1988

BOREHOLE TYPE Hollow Stem
AugerAPPROX. GROUND SURFACE
ELEVATION 185.8 m.

DEPTH Feet	DESCRIPTION	SAMPLES		GROUND WATER MONITORS
		NO	T Y P E	
0	TOPSOIL (no slag present)			
10	-red (sandstone) gravel, dark brown silt and fine sand	D5-10	ss	
	-red stony SILTY FINE SAND TILL (black stones and pebbles), cohesive, dense, moist	D5-11	▼	
	-silty medium to fine sand, black pebbles, soupy, saturated	D5-15	ss ▼	
20	-as above			
	-fine sandy clayey silt till, red, very cohesive, moist	D5-21	ss ▼	
	-red pebbly silty sand till, a few stones, dense, slightly stiff	D5-25	ss ▼	
30	-as above, weathered sandstone at tip		ss ▼	
	-red and white weathered SANDSTONE	D5-32	ss ▼	
				BOREHOLE TERMINATED
40				
50				

BOREHOLE NO. D6

PROJECT TA8873 ALGOMA STEEL

GEOLOGIST BJB

CLIENT BEAK / MOE

DATE August 3, 1988

BOREHOLE TYPE Hollow Stem Auger

APPROX. GROUND SURFACE
ELEVATION 190.15 m.

[illegible]

WELL COMPLETION DATA

MONITORING WELL	BOREHOLE DEPTH (ft)	BOREHOLE DEPTH (m)	SCREEN INTERVAL (depth in ft)		SCREEN INTERVAL (depth in m)		SANDPACK INTERVAL (depth in ft)		SANDPACK INTERVAL (depth in m)		SEAL INTERVAL (depth in ft)		SEAL INTERVAL (depth in m)	
			from	to	from	to	from	to	from	to	from	to	from	to
A1-1	56.6	17.3	54.5	49.5	16.6	15.1	54.5	47.5	16.6	14.5	47.5	25.0	14.5	7.6
A1-2	31.0	9.4	31.0	26.0	9.4	7.9	31.0	25.3	9.4	7.7	3.0	0.0	0.9	0.0
A2-1	48.8	14.9	48.8	43.8	14.9	13.4	48.8	42.8	14.9	13.0	25.3	0.0	7.7	0.0
A2-2	24.3	7.4	24.3	19.3	7.4	5.9	24.3	18.0	7.4	5.5	42.8	35.8	13.0	10.9
A3	16.5	5.0	14.6	9.6	4.5	2.9	14.6	7.8	4.5	2.4	5.0	0.0	1.5	0.0
A4-1	55.0	16.8	55.0	45.0	16.8	13.7	55.0	44.8	16.8	13.7	18.0	15.2	5.5	0.0
A4-2	13.4	4.1	13.4	8.4	4.1	2.6	13.4	6.6	4.1	2.0	5.0	0.0	1.5	0.0
A5	16.5	5.0	15.3	10.3	4.7	3.1	15.3	8.3	4.7	2.5	7.8	5.7	2.4	1.7
A6	17.0	5.2	14.8	9.8	4.5	3.0	14.8	8.8	4.5	2.7	2.0	0.0	0.6	0.0
A7-1	157.0	47.9									44.8	16.0	13.7	4.9
A7-2	41.5	12.6	34.0	24.0	10.4	7.3	34.0	12.0	10.4	3.7	2.0	0.0	0.6	0.0
B1	20.0	6.1	17.5	12.5	5.3	3.8	17.5	9.0	5.3	2.7	148.0	0.0	45.1	0.0
B2-1	75.0	21.6	71.0	66.0	21.6	20.1	71.0	60.3	21.6	18.4	2.0	0.0	0.9	0.0
B2-2	15.0	4.6	15.0	10.0	4.6	3.0	15.0	7.5	4.6	2.3	8.8	6.9	2.7	2.1
B3	19.5	5.9	17.5	12.5	5.3	3.8	17.5	8.5	5.3	2.6	3.0	0.0	0.9	0.0
B4-1	76.0	23.2	74.0	69.0	22.6	21.0	74.0	68.5	22.6	20.9	2.0	0.0	0.6	0.0
B4-2	19.0	5.8	19.0	14.0	5.8	4.3	19.0	7.0	5.8	2.1	8.5	8.0	2.6	2.4
B5	18.2	5.5	18.2	13.2	5.5	4.0	18.2	5.0	5.5	1.5	5.0	0.0	1.5	0.0
C1	33.0	10.1	29.6	24.6	9.0	7.5	29.6	23.0	9.0	7.0	68.5	0.0	20.9	0.0
C2-1	28.6	8.7	28.6	25.6	8.7	7.8	28.6	24.5	8.7	7.5	7.0	0.0	2.1	0.0
C2-2	18.2	5.5	18.2	13.2	5.5	4.0	18.2	11.2	5.5	3.4	2.0	0.0	0.6	0.0
C3	26.5	8.1	24.9	19.9	7.6	6.1	24.9	18.0	7.6	5.5	8.5	8.0	2.6	2.4
C4	17.0	5.2	14.3	9.3	4.4	2.8	14.3	8.0	4.4	2.4	5.0	0.0	1.5	0.0
D1-1	53.0	16.2	44.3	39.3	13.5	12.0	44.3	35.0	13.5	10.7	15.0	14.7	4.6	4.5
D1-2	18.8	5.7	18.8	8.8	5.7	2.7	18.8	7.0	5.7	2.1	3.0	0.0	0.9	0.0
D2	18.8	5.7	18.8	13.8	5.7	4.2	18.8	9.8	5.7	3.0	35.0	25.0	10.7	7.6
D3-1	66.8	20.4	66.8	61.8	20.4	18.8	66.8	60.5	20.4	18.4	3.0	0.0	0.9	0.0
D3-2	17.1	5.2	17.1	12.1	5.2	3.7	17.1	11.1	5.2	3.4	7.0	0.0	2.1	0.0
D4	18.8	5.7	16.8	11.8	5.1	3.6	16.8	8.5	5.1	2.6	9.8	0.0	3.0	0.0
D5-1	32.3	9.8	31.3	29.3	9.5	8.9	31.3	28.6	9.5	8.7	2.5	0.0	0.8	0.0
D5-2	19.6	6.0	19.6	9.6	6.0	2.9	19.6	9.3	6.0	2.8	60.5	13.5	18.4	4.1
D6	20.0	6.1	17.5	12.5	5.3	3.8	17.5	11.9	5.3	3.6	2.0	0.0	0.6	0.0

WELL DEVELOPMENT DATA

Piezometer #	Date (yy/mm/dd)	Water Level (initial) (mbtc)	Total Depth (m)	Bore Volume (L)	Bore Volume Removed (L)	pH	Conductivity	Temperature (celsius)	Water Level (final) (mbtc)
A1-1	88/08/24	6.68	17.70	23	23	6.60	-	-	-
					46	6.46	-	-	-
					69	6.38	-	-	-
					92	6.43	-	-	-
					115	6.43	-	-	-
					138	-	-	-	NR
A1-2	88/08/24	6.69	10.45	8	8	7.93	-	-	-
					16	7.41	-	-	-
					24	7.35	-	-	-
					32	7.24	-	-	-
					40	7.26	-	-	-
					48	7.31	-	-	NR
A2-1	88/08/07	5.80	14.88	20	14	10.20	200	15	-
					21	10.81	290	16	14.68
					28	12.23	260	14	14.37
A2-2	88/08/07	6.46	7.42	4	7	9.89	820	14	-
					10	9.99	810	14	-
					14	10.0	950	14	-
					17	10.07	790	14	6.53
A3	88/08/24	0.98	5.28	9	9	7.50	-	-	-
					18	7.36	-	-	-
					27	7.57	-	-	-
					36	7.46	-	-	-
					45	7.54	-	-	-
					54	8.15	-	-	-
					63	8.45	-	-	-
					72	8.38	-	-	1.10
A4-1	88/08/24 88/08/25	0.88	16.71	33	33	8.77	-	-	15.38
					66	9.19	-	-	DRY
A4-2	88/08/24	1.29	4.96	8	8	7.01	-	-	-
					16	7.02	-	-	-
					24	7.04	-	-	-
					32	7.04	-	-	-
					40	6.99	-	-	-
					48	7.03	-	-	1.31
A5	88/08/07	3.26	4.65	5	5	12.13	3440	14	-
					10	11.91	1470	14	-
					14	11.88	1020	14	-
					16	11.85	1070	14	4.32
A6	88/08/07	1.85	4.50	7	7	11.86	290	16	-
					11	11.97	240	14	-
					17	12.03	230	14	-
					23	11.95	270	14	3.95
A7-2	88/08/24	1.88	11.32	19	8	-	-	-	-
					27	-	-	-	-
					46	8.33	-	-	-
					65	8.31	-	-	-
					84	8.24	-	-	-
					103	8.34	-	-	8.0

Piezometer #	Date (yy/mm/dd)	Water Level (initial) (mbtc)	Total Depth (m)	Bore Volume (L)	Bore Volume Removed (L)	pH	Conductivity	Temperature (celsius)	Water Level (final) (mbtc)
B-1	88/08/14 88/08/25	2.10	6.16	9	18 52	- -	- -	- -	- NR
B2-1	88/08/14 88/08/25	22.40	1.55	44	22 65	- -	- -	- -	- DRY
B2-2	88/08/14 88/08/25	5.30	2.63	6	20 26 32 38 44 50	- 7.25 7.65 7.55 7.55 7.54	- - - - - -	- - - - - -	- - - - - NR
B3	88/08/24	2.69	6.32	8	8 16 24 32	11.97 11.97 12.04 12.06	- - - -	- - - -	- - - 2.67
B4-2	88/08/24	3.69	6.57	6	6 12 18 24	12.34 12.32 12.32 12.31	- - - -	- - - -	- - - 3.72
B4-1	88/08/24	3.16	22.57	41	41 82	10.19 10.97	- -	- -	- DRY
B5	88/08/24	3.53	6.34	6	5 10 15 20 25	- 12.46 12.47 12.45 12.46	- - - - -	- - - - -	- - - - 3.52
C1	88/08/07	7.72	9.02	6	6 12 18 21	10.95 10.88 10.91 10.91	2480 2520 2510 2550	14 14 14 14	- - - 8.46
C2-1	88/08/05 88/08/06	6.13	8.70	6	6 9 10 15 18	- - - - -	1620 1690 1710 1630 1680	15 17 - 15 14	- - - - 9.10
C2-2	88/08/05	Dry	5.55	-	-	-	-	-	-
C3	88/08/05	7.14	7.57	4	4 8 10 12	- - - -	740 630 700 700	15 14 15 14	- - - 7.67
C4	88/08/05	4.09	4.37	3	7 10 14	- - -	1390 1380 1370	14 14 14	- - 4.09

Piezometer #	Date (yy/mm/dd)	Water Level (initial) (mbtc)	Total Depth (m)	Bore Volume (L)	Bore Volume Removed (L)	pH	Conductivity	Temperature (celsius)	Water Level (final) (mbtc)			
D1-1	88/08/05	3.55	16.15	28	28	-	1040	15	-			
					56	-	1180	14	-			
					84	-	1170	14	3.54			
D1-2	88/08/05	3.67	5.74	7	7	-	2130	15	-			
					14	-	2160	14	-			
					21	-	2240	14	-			
					28	-	2210	14	3.50			
D2	88/08/05	4.22	5.71	3	3	-	141	11	-			
					8	-	139	11	-			
					14	-	138	11	-			
					17	-	138	11	4.25			
D3-1	88/08/06	2.62	20.3	20	20	9.94	2390	11	-			
					40	10.05	4450	12	-			
					50	10.43	2510	13	-			
					60	10.48	2250	13	14.00			
	88/08/07				73	10.43	2560	12	13.94			
D3-2	88/08/06	2.75	4.88	6	7	10.19	800	12	-			
					14	10.26	760	12	-			
					21	10.32	810	12	-			
					28	10.40	800	12	NR			
D4	88/08/06	3.26	5.10	6	7	9.66	3560	12	-			
					14	9.73	3860	12	-			
					21	9.88	3340	12	-			
					28	9.86	3320	12	3.05			
D5-1	88/08/06	3.16	9.55	14	11	9.72	600	12	-			
					14	9.77	1010	10	-			
					19	10.58	1080	12	-			
					28	11.11	1050	13	9.80			
	88/08/07				35	10.25	1000	11	-			
					46	10.28	1020	12	9.98			
D5-2	88/08/06	3.28	5.97	7	7	9.50	1120	11	-			
					14	9.88	1220	10	-			
					19	9.70	1290	11	-			
					21	9.60	1800	11	-			
					25	9.86	1770	11	6.00			
D6	88/08/06	5.13	5.33	2	3	9.50	1550	12	-			
					6	9.48	1670	12	-			
					8	10.78	1820	14	5.77			

APPENDIX 3

Hydraulic Conductivity Data

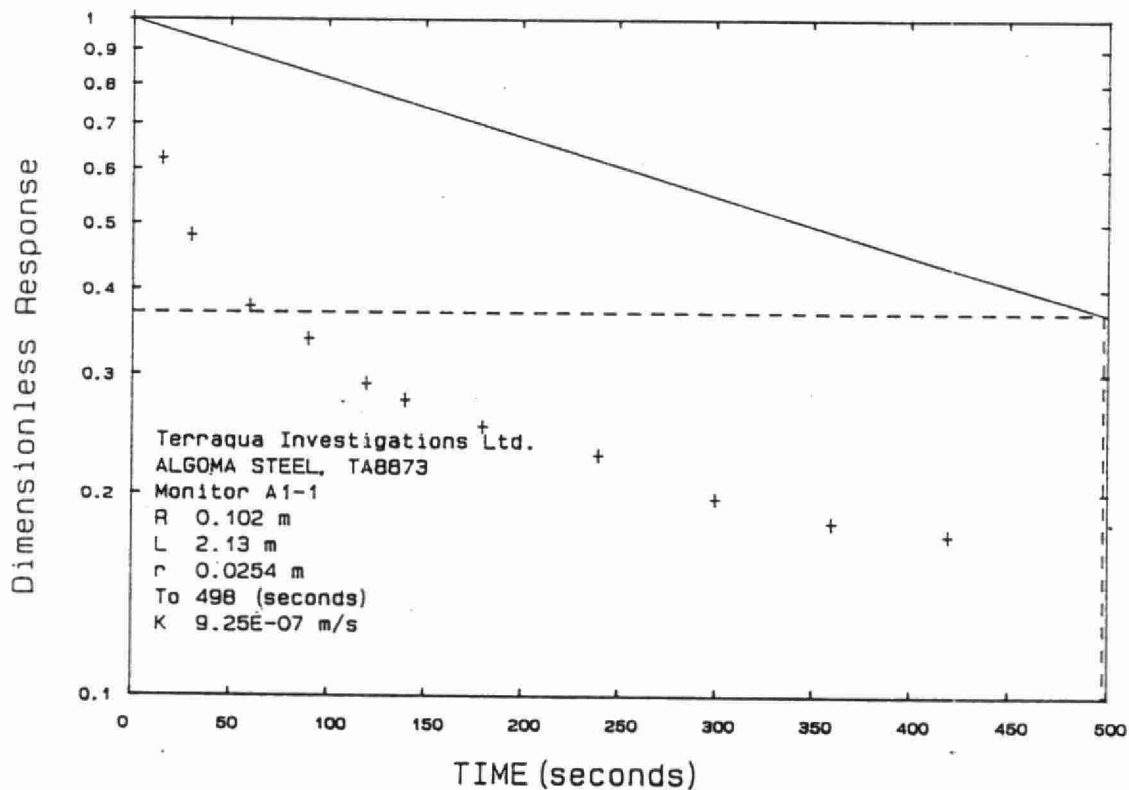
WELL RESPONSE TEST RESULTS

SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID A1-1
 Static water level (mBTOP) 6.765
 Initial water level (mBTOP) 7.4
 Screen length (m) 2.13
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/ 8/25	11:11: 0	0	7.40	1.000
2	88/ 8/25	11:11:15	15	7.16	0.622
3	88/ 8/25	11:11:30	30	7.07	0.480
4	88/ 8/25	11:12: 0	60	7.00	0.378
5	88/ 8/25	11:12:30	90	6.98	0.339
6	88/ 8/25	11:13: 0	120	6.95	0.291
7	88/ 8/25	11:13:20	140	6.94	0.276
8	88/ 8/25	11:14: 0	180	6.92	0.252
9	88/ 8/25	11:15: 0	240	6.91	0.228
10	88/ 8/25	11:16: 0	300	6.89	0.197
11	88/ 8/25	11:17: 0	360	6.88	0.181
12	88/ 8/25	11:18: 0	420	6.87	0.173
13	88/ 8/25	11:21: 0	600	6.86	0.150

SLUG TEST ANALYSIS

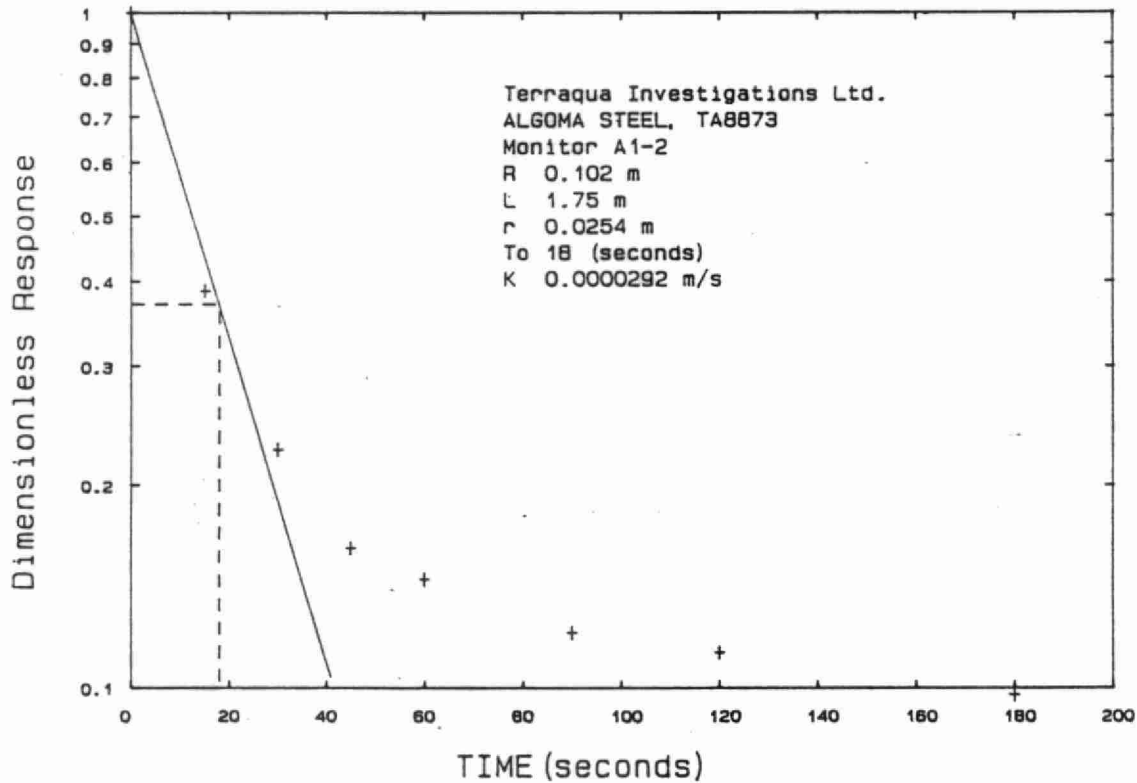


SLUG TEST DATA

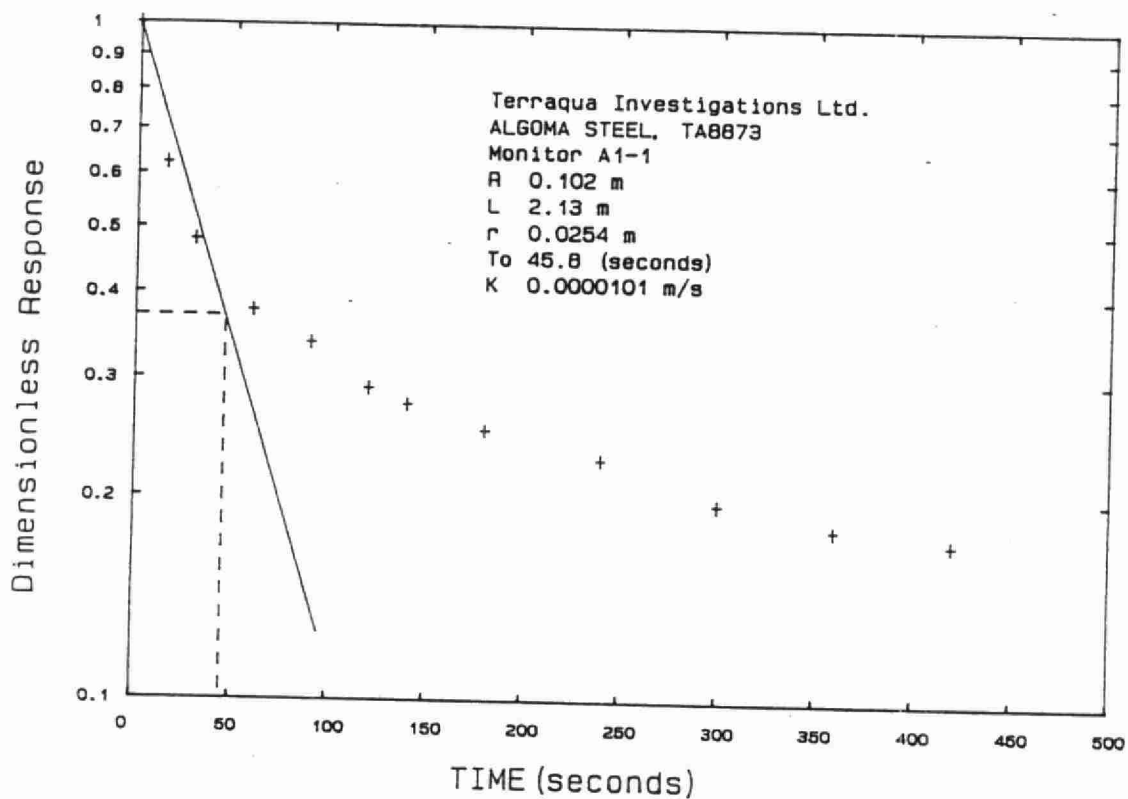
Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID A1-2
 Static water level (mBTOP) 6.69
 Initial water level (mBTOP) 7.31
 Screen length (m) 1.75
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/ 8/25	11:25: 0	0	7.31	1.000
2	88/ 8/25	11:25:15	15	6.93	0.387
3	88/ 8/25	11:25:30	30	6.83	0.226
4	88/ 8/25	11:25:45	45	6.79	0.161
5	88/ 8/25	11:26: 0	60	6.78	0.145
6	88/ 8/25	11:26:30	90	6.76	0.121
7	88/ 8/25	11:27: 0	120	6.76	0.113
8	88/ 8/25	11:28: 0	180	6.75	0.097
9	88/ 8/25	11:29: 0	240	6.74	0.089

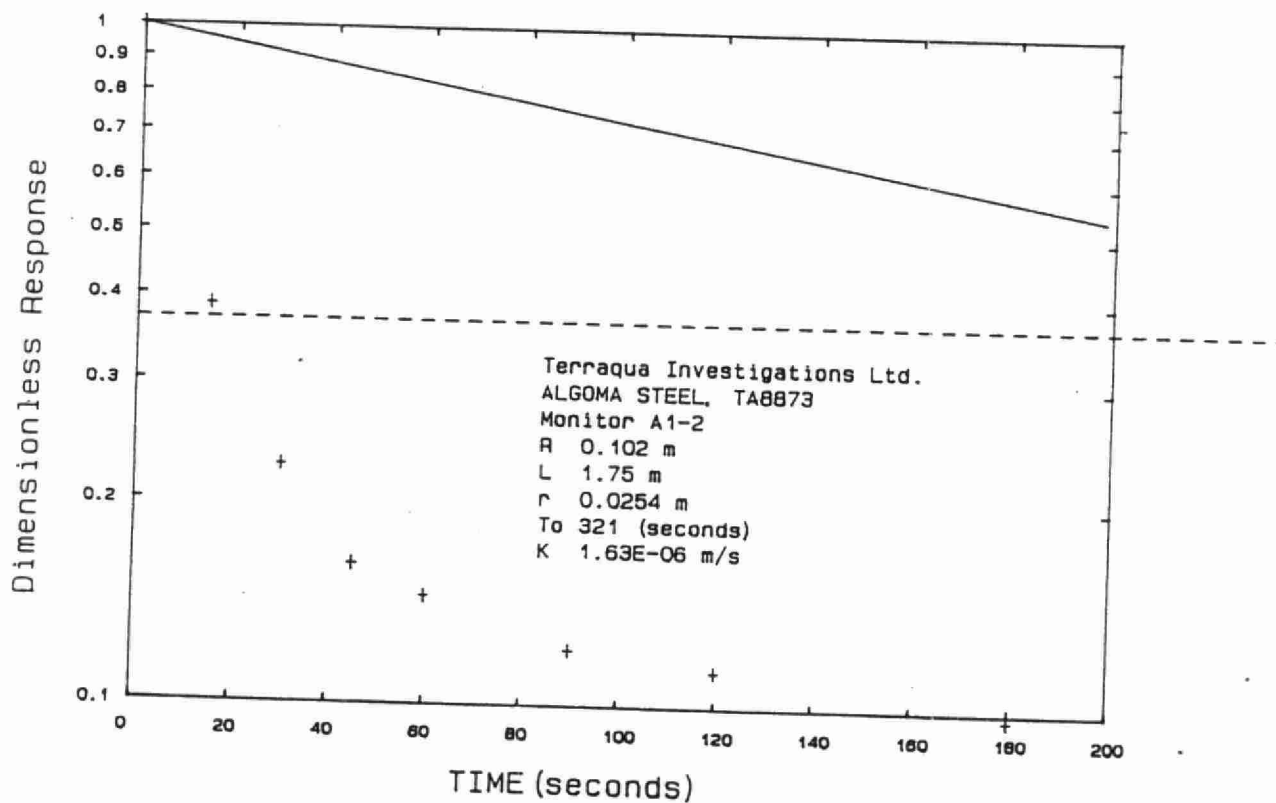
SLUG TEST ANALYSIS



SLUG TEST ANALYSIS



SLUG TEST ANALYSIS

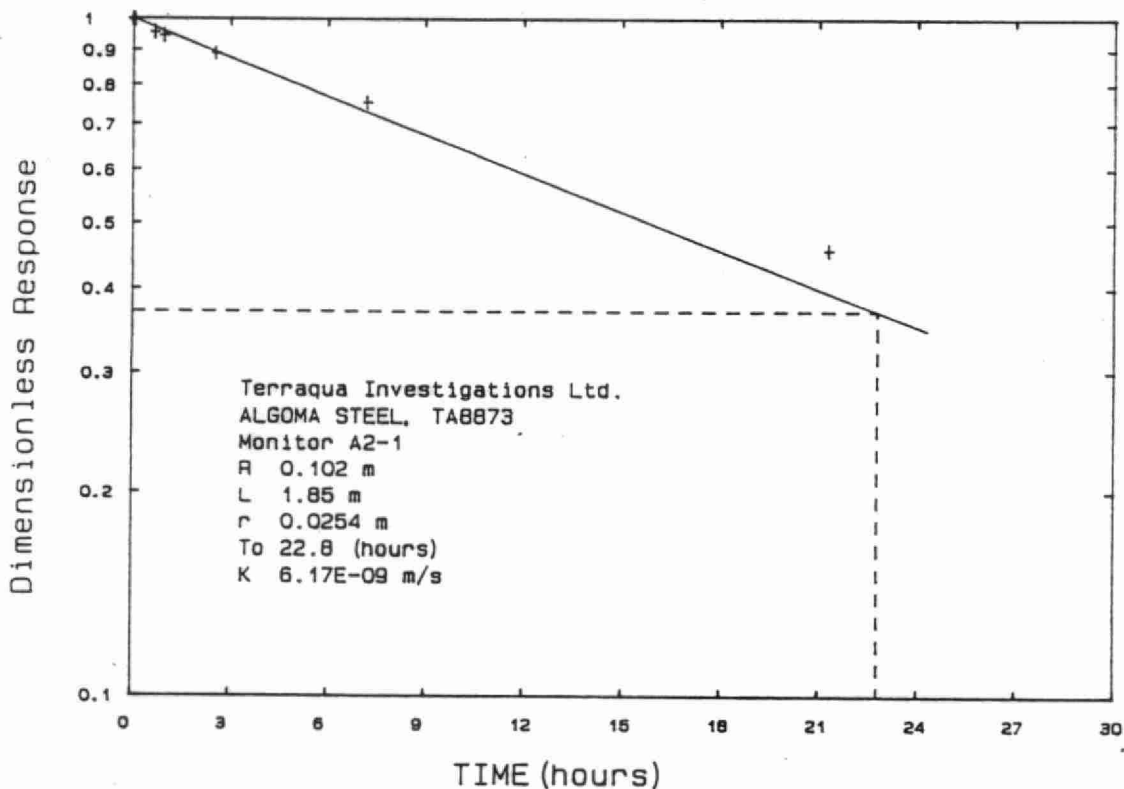


SLUG TEST DATA

Project name	ALGOMA STEEL
Project number	TA8873
Monitor ID	A2-1
Static water level (mBTOP)	5.55
Initial water level (mBTOP)	14.37
Screen length (m)	1.85
Screen radius (m)	0.1016
Piezometer radius (m)	0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	12: 9: 0	0.0	14.37	1.000
2	88/10/19	12: 9:30	0.5	14.36	0.999
3	88/10/19	12:10: 0	1.0	14.36	0.999
4	88/10/19	12:10:30	1.5	14.35	0.998
5	88/10/19	12:12: 0	3.0	14.34	0.997
6	88/10/19	12:49: 0	40.0	13.98	0.956
7	88/10/19	13: 6:30	57.5	13.89	0.946
8	88/10/19	14:41:30	152.5	13.41	0.891
9	88/10/19	19:21: 0	432.0	12.21	0.755
10	88/10/20	9:29: 0	1280.0	9.58	0.457

SLUG TEST ANALYSIS

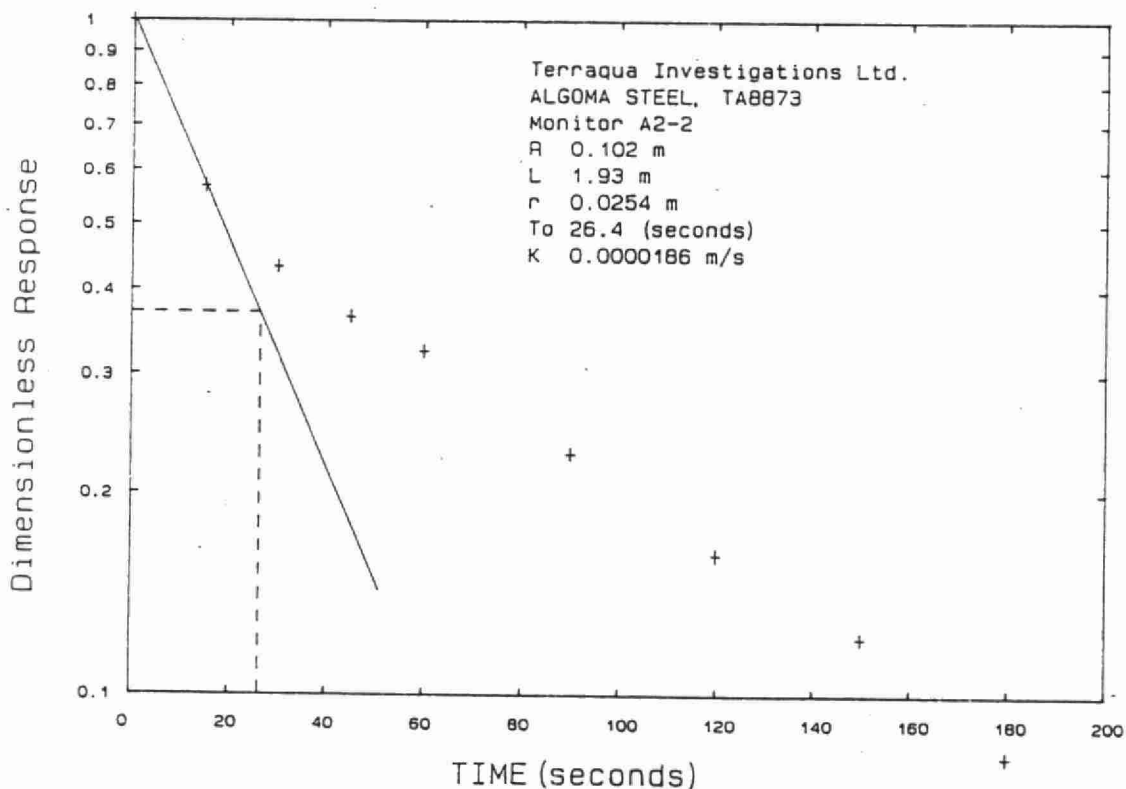


SLUG TEST DATA

Project name	ALGOMA STEEL
Project number	TA8873
Monitor ID	A2-2
Static water level (mBTOP)	6.3
Initial water level (mBTOP)	6.67
Screen length (m)	1.93
Screen radius (m)	0.1016
Piezometer radius (m)	0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	12:44: 0	0	6.67	1.000
2	88/10/19	12:44:15	15	6.51	0.568
3	88/10/19	12:44:30	30	6.46	0.432
4	88/10/19	12:44:45	45	6.43	0.365
5	88/10/19	12:45: 0	60	6.42	0.324
6	88/10/19	12:45:30	90	6.38	0.230
7	88/10/19	12:46: 0	120	6.36	0.162
8	88/10/19	12:46:30	150	6.34	0.122
9	88/10/19	12:47: 0	180	6.33	0.081
10	88/10/19	12:47:30	210	6.32	0.054

SLUG TEST ANALYSIS

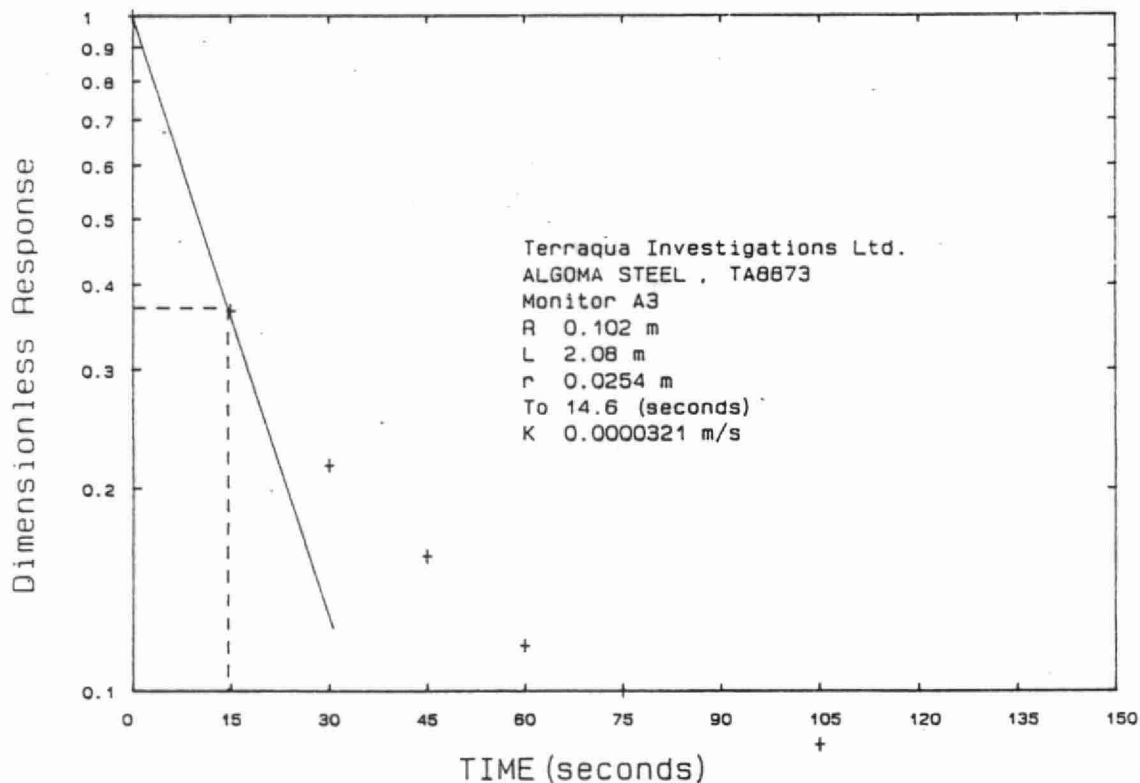


SLUG TEST DATA

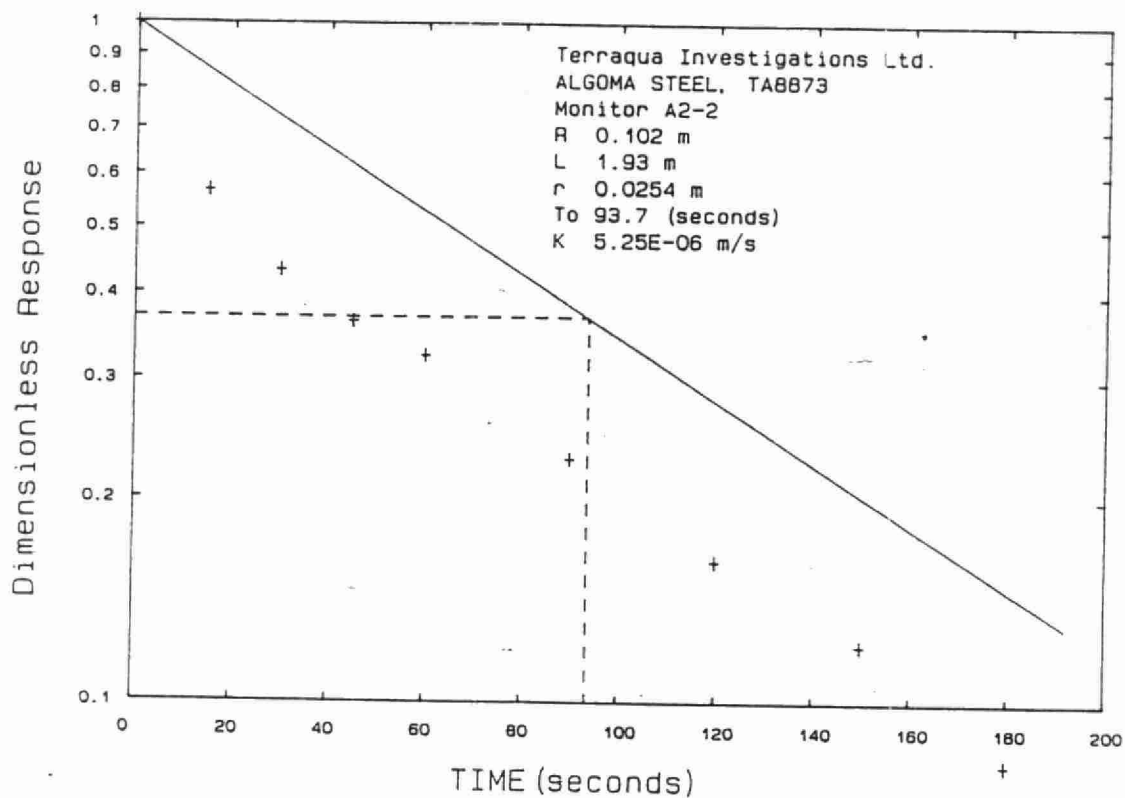
Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID A3
 Static water level (mBTOP) 0.79
 Initial water level (mBTOP) 1.39
 Screen length (m) 2.08
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	15: 7: 0	0	1.39	1.000
2	88/10/19	15: 7:15	15	1.01	0.367
3	88/10/19	15: 7:30	30	0.92	0.217
4	88/10/19	15: 7:45	45	0.88	0.158
5	88/10/19	15: 8: 0	60	0.86	0.117
6	88/10/19	15: 8:15	75	0.85	0.100
7	88/10/19	15: 8:45	105	0.84	0.083
8	88/10/19	15: 9:15	135	0.83	0.067
9	88/10/19	15: 9:45	165	0.82	0.050

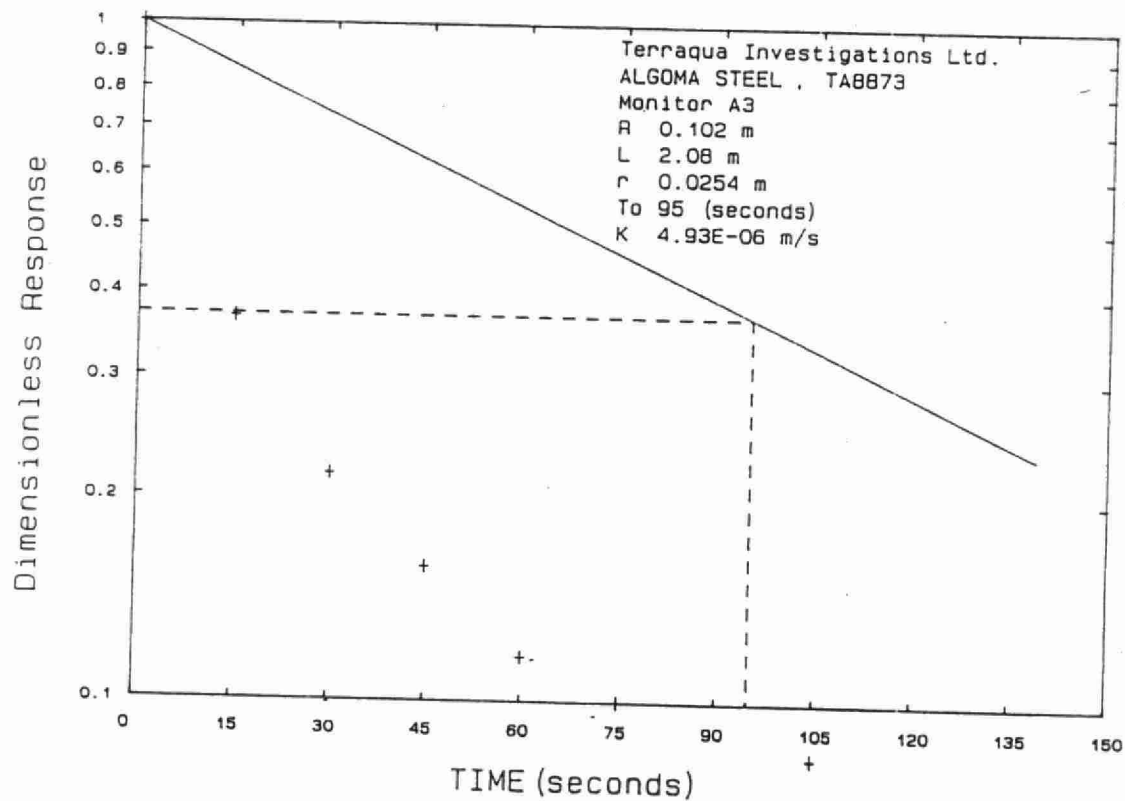
SLUG TEST ANALYSIS



SLUG TEST ANALYSIS



SLUG TEST ANALYSIS

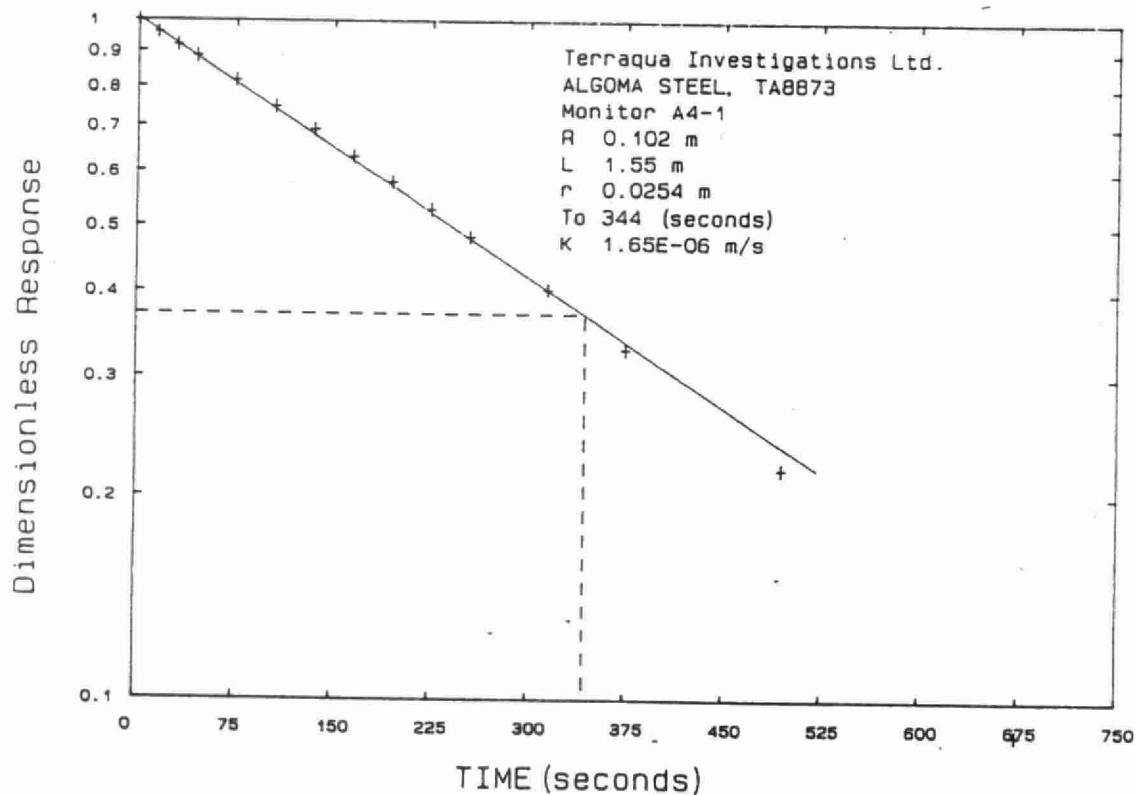


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID A4-1
 Static water level (mBTOP) 0.83
 Initial water level (mBTOP) 5.05
 Screen length (m) 1.55
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	16:44:45	0	5.05	1.000
2	88/10/19	16:45: 0	15	4.88	0.960
3	88/10/19	16:45:15	30	4.71	0.919
4	88/10/19	16:45:30	45	4.57	0.886
5	88/10/19	16:46: 0	75	4.28	0.818
6	88/10/19	16:46:30	105	3.99	0.749
7	88/10/19	16:47: 0	135	3.75	0.692
8	88/10/19	16:47:30	165	3.49	0.630
9	88/10/19	16:48: 0	195	3.27	0.578
10	88/10/19	16:48:30	225	3.06	0.528
11	88/10/19	16:49: 0	255	2.86	0.482
12	88/10/19	16:50: 0	315	2.53	0.403
13	88/10/19	16:51: 0	375	2.22	0.329
14	88/10/19	16:53: 0	495	1.76	0.220
15	88/10/19	16:56: 0	675	1.21	0.090
16	88/10/19	16:57:45	780	1.10	0.064

SLUG TEST ANALYSIS

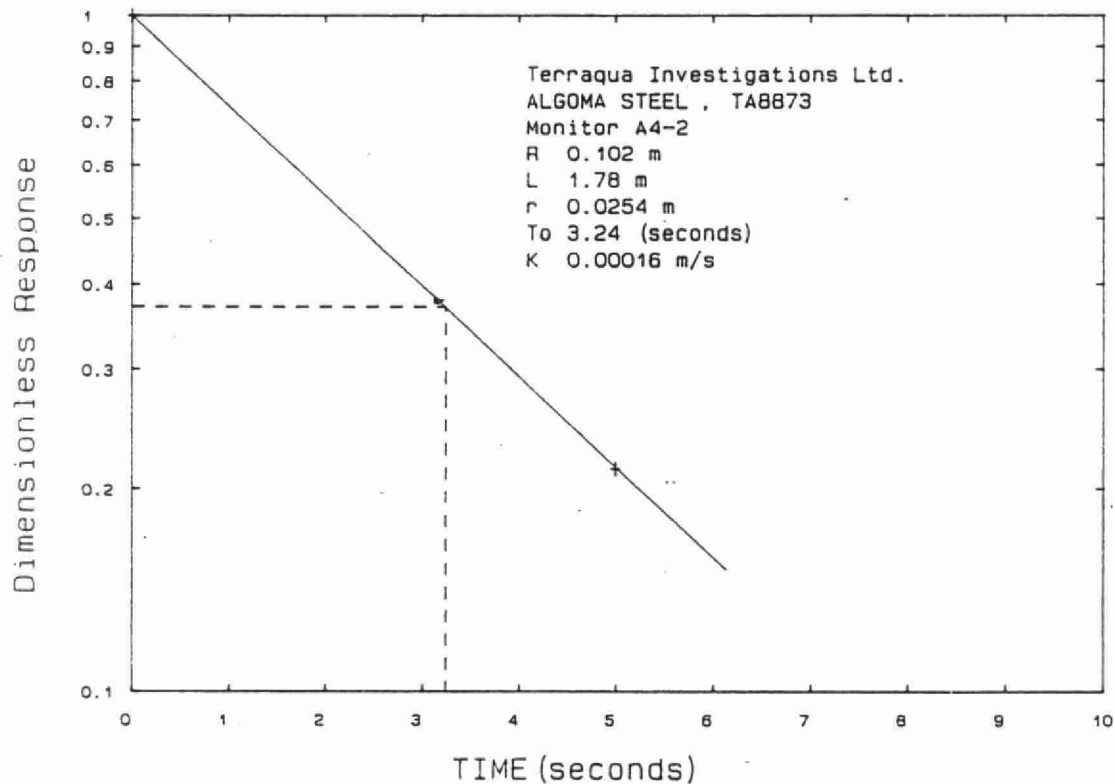


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID A4-2
 Static water level (mBTOP) 1.25
 Initial water level (mBTOP) 1.32
 Screen length (m) 1.78
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	15:28: 0	0	1.32	1.000
2	88/10/19	15:28: 5	5	1.26	0.214
3	88/10/19	15:28:15	15	1.26	0.143

SLUG TEST ANALYSIS

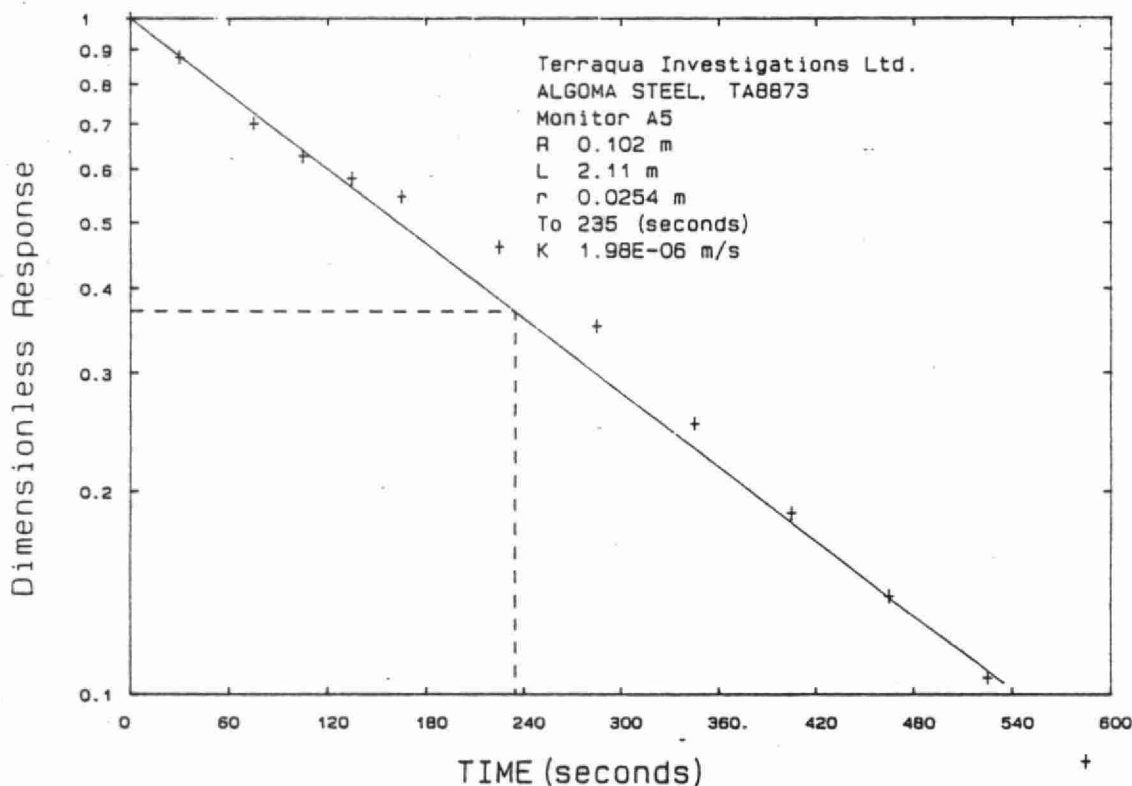


SLUG TEST DATA

Project name - ALGOMA STEEL
 Project number TA8873
 Monitor ID A5
 Static water level (mBTOP) 3.135
 Initial water level (mBTOP) 4.88
 Screen length (m) 2.11
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	10:45:15	0	4.88	1.000
2	88/10/19	10:45:45	30	4.66	0.877
3	88/10/19	10:46:30	75	4.36	0.702
4	88/10/19	10:47: 0	105	4.23	0.628
5	88/10/19	10:47:30	135	4.15	0.582
6	88/10/19	10:48: 0	165	4.09	0.547
7	88/10/19	10:49: 0	225	3.94	0.461
8	88/10/19	10:50: 0	285	3.75	0.352
9	88/10/19	10:51: 0	345	3.57	0.252
10	88/10/19	10:52: 0	405	3.46	0.186
11	88/10/19	10:53: 0	465	3.38	0.140
12	88/10/19	10:54: 0	525	3.32	0.106
13	88/10/19	10:55: 0	585	3.27	0.080

SLUG TEST ANALYSIS

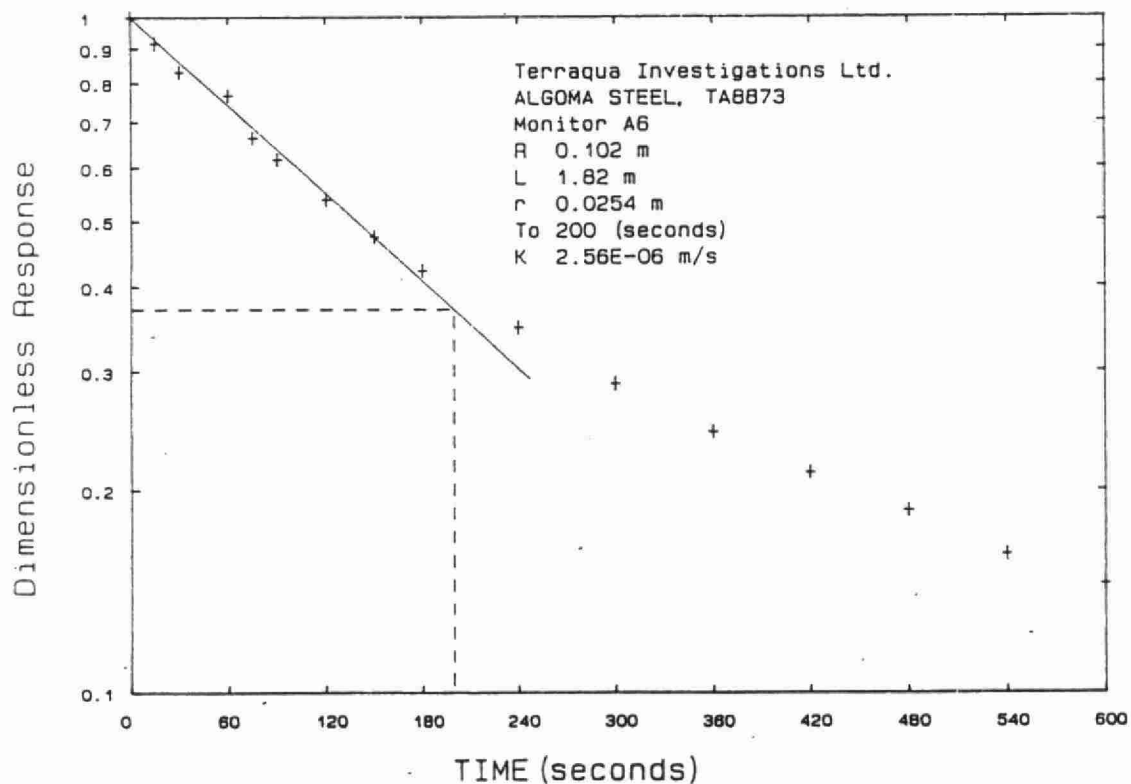


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID A6
 Static water level (mBTOP) 1.42
 Initial water level (mBTOP) 3.35
 Screen length (m) 1.82
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	10:43: 0	0	3.35	1.000
2	88/10/19	10:43:15	15	3.19	0.917
3	88/10/19	10:43:30	30	3.02	0.832
4	88/10/19	10:44: 0	60	2.90	0.767
5	88/10/19	10:44:15	75	2.70	0.663
6	88/10/19	10:44:30	90	2.61	0.617
7	88/10/19	10:45: 0	120	2.46	0.539
8	88/10/19	10:45:30	150	2.33	0.474
9	88/10/19	10:46: 0	180	2.23	0.422
10	88/10/19	10:47: 0	240	2.09	0.347
11	88/10/19	10:48: 0	300	1.97	0.288
12	88/10/19	10:49: 0	360	1.89	0.244
13	88/10/19	10:50: 0	420	1.83	0.212
14	88/10/19	10:51: 0	480	1.78	0.187
15	88/10/19	10:52: 0	540	1.73	0.161
16	88/10/19	10:53: 0	600	1.70	0.145

SLUG TEST ANALYSIS

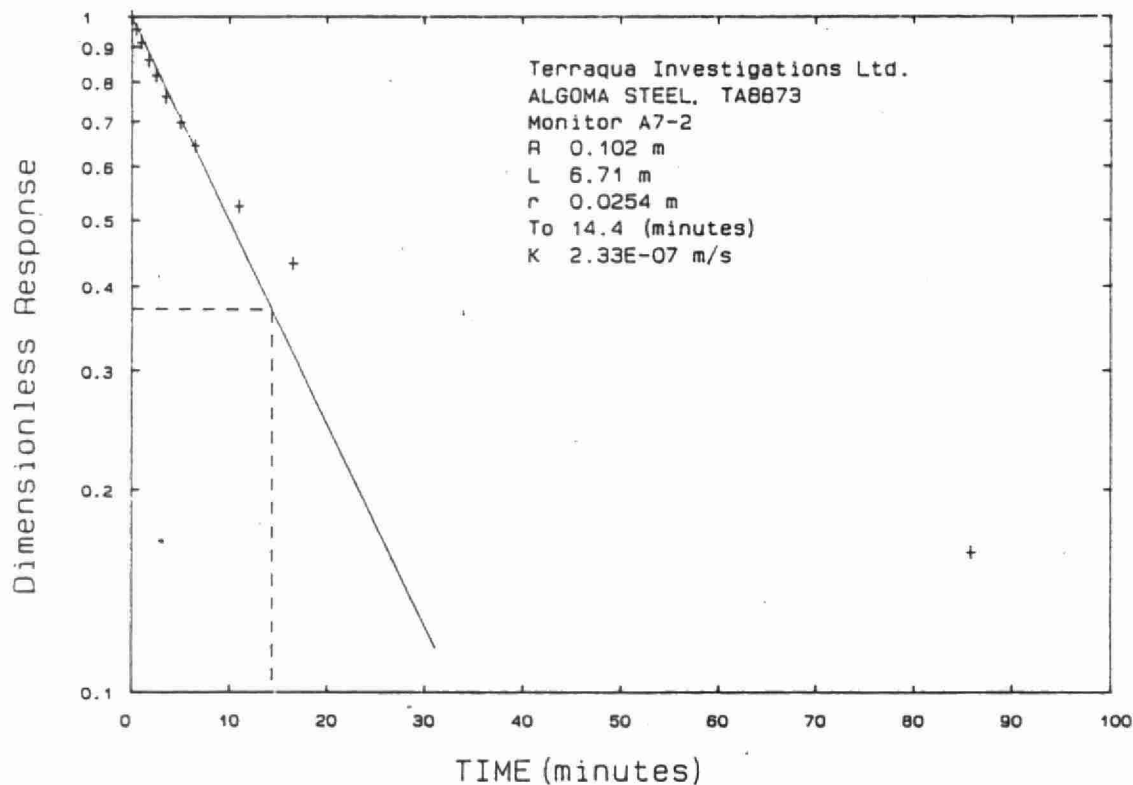


SLUG TEST DATA

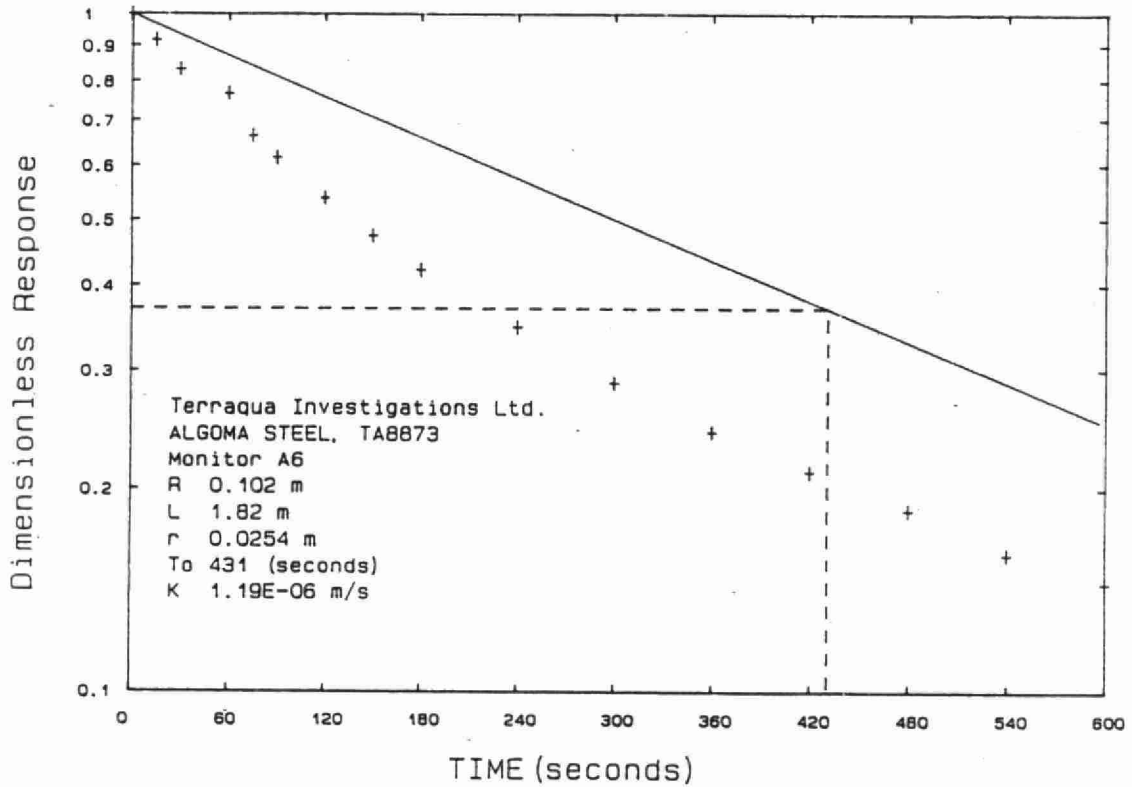
Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID A7-2
 Static water level (mBTOP) 1.875
 Initial water level (mBTOP) 6.17
 Screen length (m) 6.71
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/ 8/25	14:16:30	0.0	6.17	1.000
2	88/ 8/25	14:17: 0	0.5	5.98	0.956
3	88/ 8/25	14:17:30	1.0	5.80	0.914
4	88/ 8/25	14:18:15	1.7	5.58	0.863
5	88/ 8/25	14:19: 0	2.5	5.39	0.818
6	88/ 8/25	14:20: 0	3.5	5.15	0.763
7	88/ 8/25	14:21:30	5.0	4.87	0.698
8	88/ 8/25	14:23: 0	6.5	4.64	0.644
9	88/ 8/25	14:27:30	11.0	4.13	0.525
10	88/ 8/25	14:33: 0	16.5	3.73	0.433
11	88/ 8/25	15:42:15	85.7	2.57	0.162

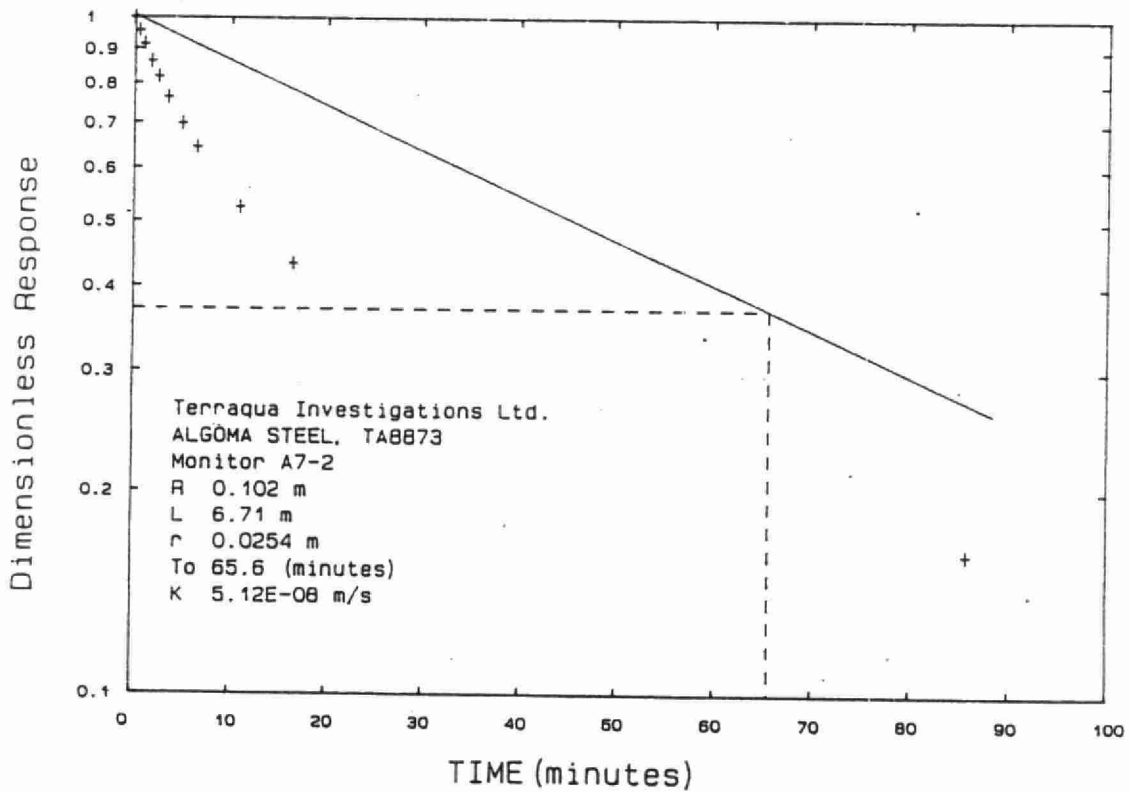
SLUG TEST ANALYSIS



SLUG TEST ANALYSIS



SLUG TEST ANALYSIS

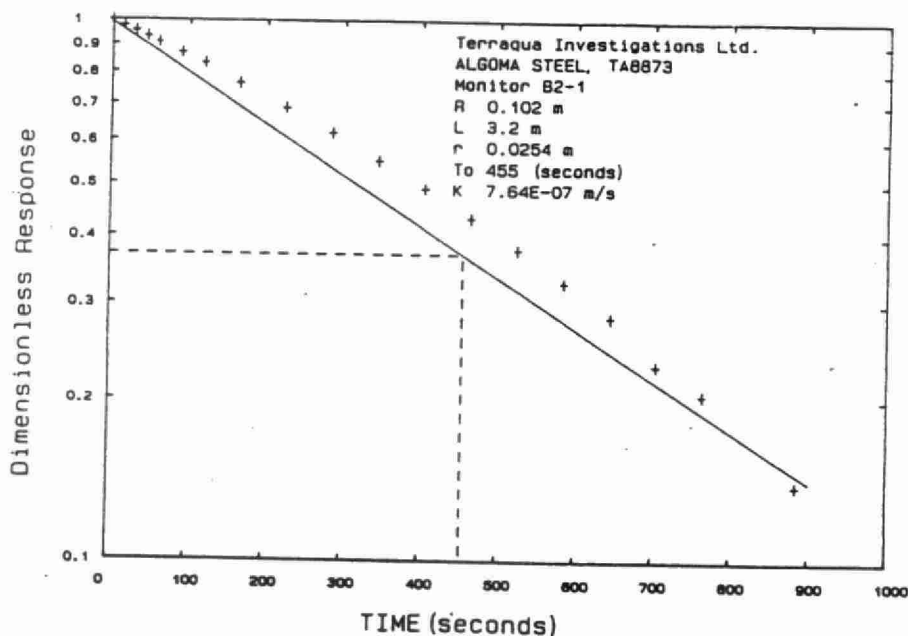


SLUG TEST DATA

Project name	ALGOMA STEEL
Project number	TA8873
Monitor ID	B2-1
Static water level (mBTOP)	1.605
Initial water level (mBTOP)	8.91
Screen length (m)	3.2
Screen radius (m)	0.1016
Piezometer radius (m)	0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	9: 7:15	0.0	8.91	1.000
2	88/10/19	9: 7:30	0.2	8.73	0.975
3	88/10/19	9: 7:45	0.5	8.57	0.953
4	88/10/19	9: 8: 0	0.7	8.41	0.932
5	88/10/19	9: 8:15	1.0	8.24	0.908
6	88/10/19	9: 8:45	1.5	7.94	0.867
7	88/10/19	9: 9:15	2.0	7.68	0.832
8	88/10/19	9:10: 0	2.7	7.19	0.765
9	88/10/19	9:11: 0	3.7	6.64	0.689
10	88/10/19	9:12: 0	4.7	6.12	0.619
11	88/10/19	9:13: 0	5.7	5.63	0.551
12	88/10/19	9:14: 0	6.7	5.18	0.489
13	88/10/19	9:15: 0	7.7	4.76	0.432
14	88/10/19	9:16: 0	8.7	4.37	0.379
15	88/10/19	9:17: 0	9.7	4.01	0.329
16	88/10/19	9:18: 0	10.7	3.68	0.284
17	88/10/19	9:19: 0	11.7	3.30	0.232
18	88/10/19	9:20: 0	12.7	3.10	0.205
19	88/10/19	9:22: 0	14.7	2.62	0.139
20	88/10/19	9:25: 0	17.7	2.11	0.069

SLUG TEST ANALYSIS

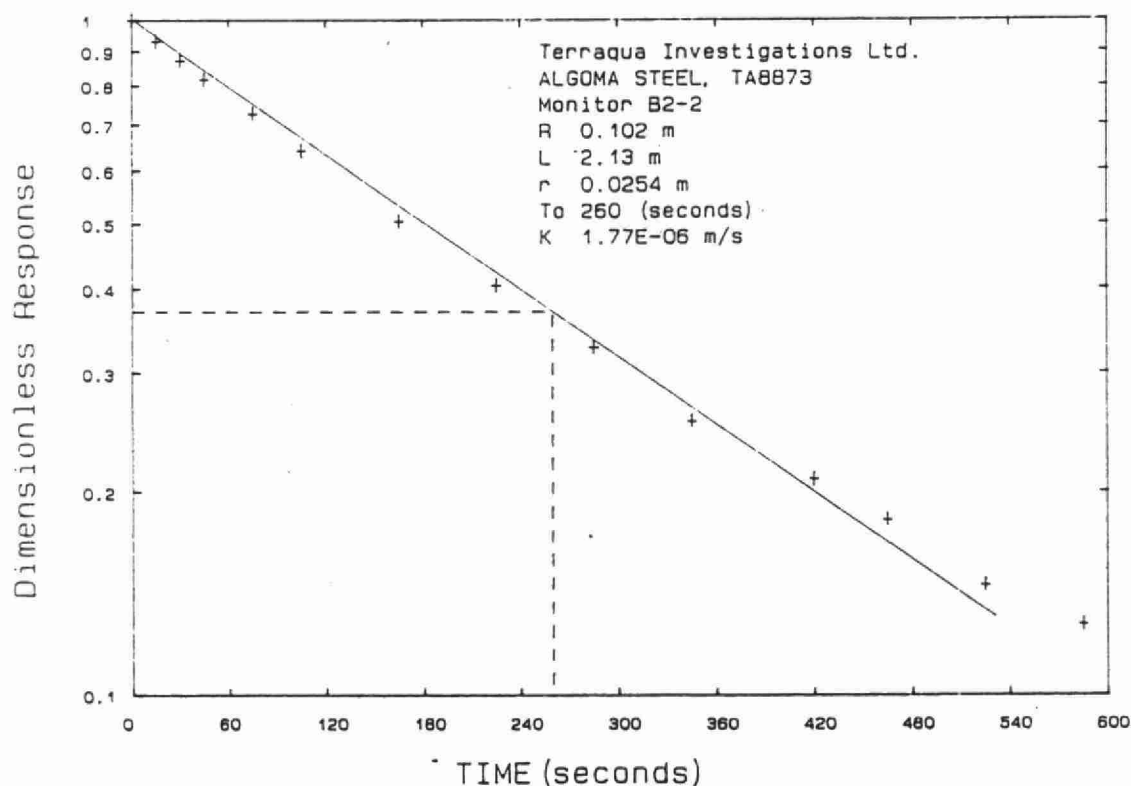


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID B2-2
 Static water level (mBTOP) 2.72
 Initial water level (mBTOP) 3.82
 Screen length (m) 2.13
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	9:40:15	0	3.82	1.000
2	88/10/19	9:40:30	15	3.74	0.932
3	88/10/19	9:40:45	30	3.68	0.873
4	88/10/19	9:41: 0	45	3.62	0.818
5	88/10/19	9:41:30	75	3.52	0.727
6	88/10/19	9:42: 0	105	3.42	0.641
7	88/10/19	9:43: 0	165	3.27	0.505
8	88/10/19	9:44: 0	225	3.16	0.405
9	88/10/19	9:45: 0	285	3.08	0.327
10	88/10/19	9:46: 0	345	3.00	0.255
11	88/10/19	9:47:15	420	2.95	0.209
12	88/10/19	9:48: 0	465	2.92	0.182
13	88/10/19	9:49: 0	525	2.88	0.145
14	88/10/19	9:50: 0	585	2.86	0.127

SLUG TEST ANALYSIS

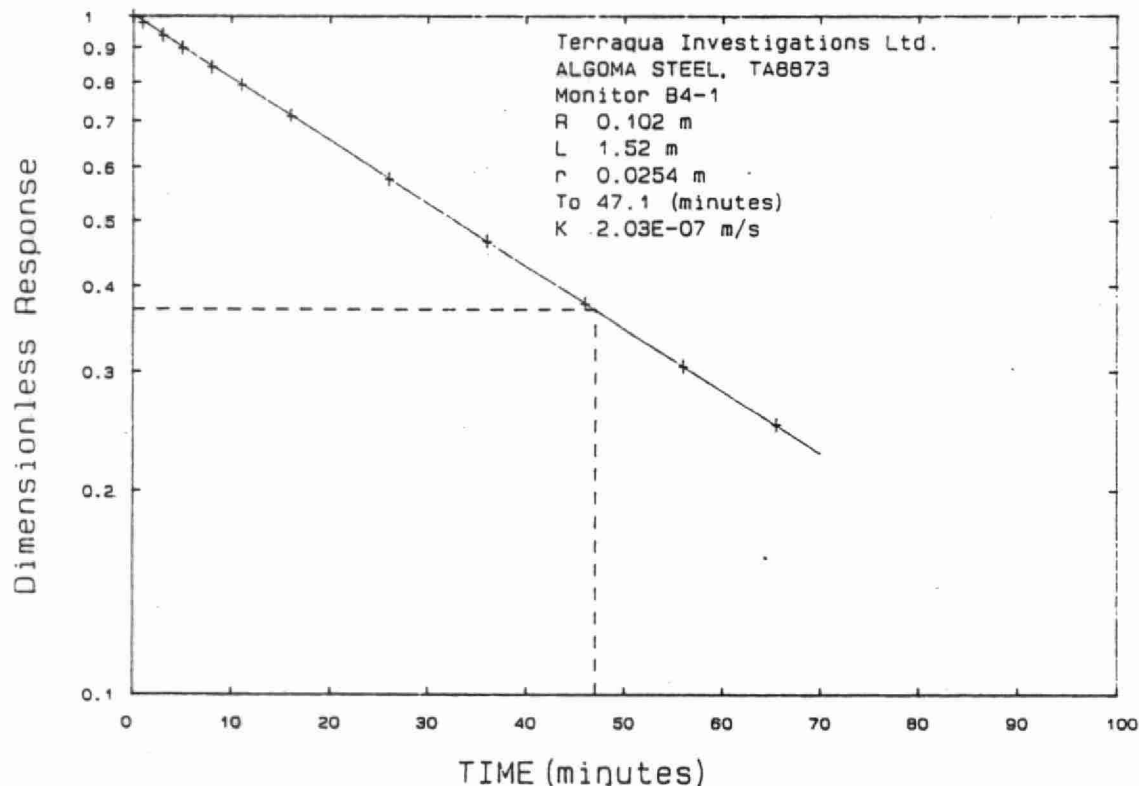


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID B4-1
 Static water level (mBTOP) 3.16
 Initial water level (mBTOP) 16.12
 Screen length (m) 1.52
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/ 8/25	12:44: 0	0.0	16.12	1.000
2	88/ 8/25	12:45: 0	1.0	15.84	0.978
3	88/ 8/25	12:47: 0	3.0	15.31	0.938
4	88/ 8/25	12:49: 0	5.0	14.81	0.899
5	88/ 8/25	12:52: 0	8.0	14.09	0.843
6	88/ 8/25	12:55: 0	11.0	13.42	0.792
7	88/ 8/25	13: 0: 0	16.0	12.40	0.713
8	88/ 8/25	13:10: 0	26.0	10.64	0.577
9	88/ 8/25	13:20: 0	36.0	9.22	0.468
10	88/ 8/25	13:30: 0	46.0	8.05	0.377
11	88/ 8/25	13:40: 0	56.0	7.13	0.306
12	88/ 8/25	13:49:30	65.5	6.41	0.251
13	88/ 8/25	15:54: 0	190.0	3.35	0.015

SLUG TEST ANALYSIS

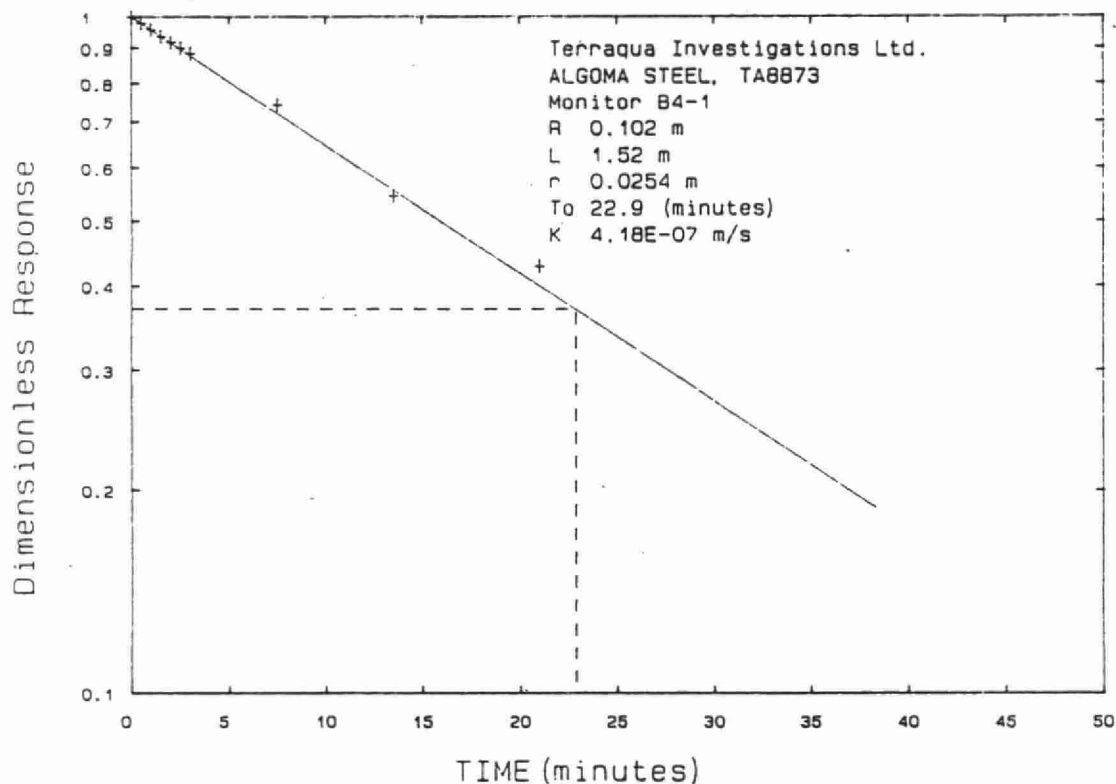


SLUG TEST DATA

Project name	ALGOMA STEEL
Project number	TA8873
Monitor ID	B4-1
Static water level (mBTOP)	3.07
Initial water level (mBTOP)	8.115
Screen length (m)	1.52
Screen radius (m)	0.1016
Piezometer radius (m)	0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/10/18	16:43: 0	0.0	8.11	1.000
2	88/10/18	16:43:30	0.5	8.00	0.978
3	88/10/18	16:44: 0	1.0	7.90	0.957
4	88/10/18	16:44:30	1.5	7.79	0.936
5	88/10/18	16:45: 0	2.0	7.70	0.918
6	88/10/18	16:45:30	2.5	7.61	0.900
7	88/10/18	16:46: 0	3.0	7.53	0.884
8	88/10/18	16:50:30	7.5	6.82	0.743
9	88/10/18	16:56:30	13.5	5.82	0.545
10	88/10/18	17: 4: 0	21.0	5.23	0.428
11	88/10/18	17:36: 0	53.0	4.08	0.200

SLUG TEST ANALYSIS

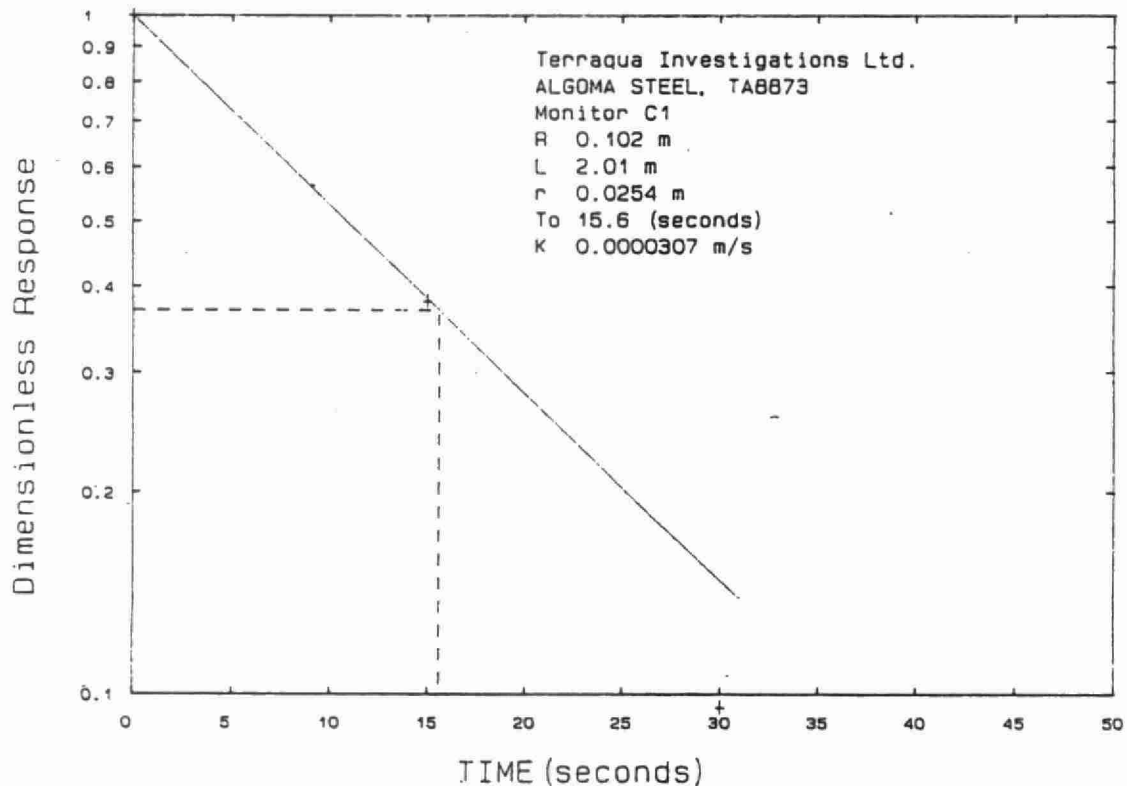


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID C1
 Static water level (mBTOP) 7.76
 Initial water level (mBTOP) 7.97
 Screen length (m) 2.01
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/18	12:50:30	0	7.97	1.000
2	88/10/18	12:50:45	15	7.84	0.381
3	88/10/18	12:51: 0	30	7.78	0.095
4	88/10/18	12:51:12	42	7.76	%-1.3858966885E-10

SLUG TEST ANALYSIS

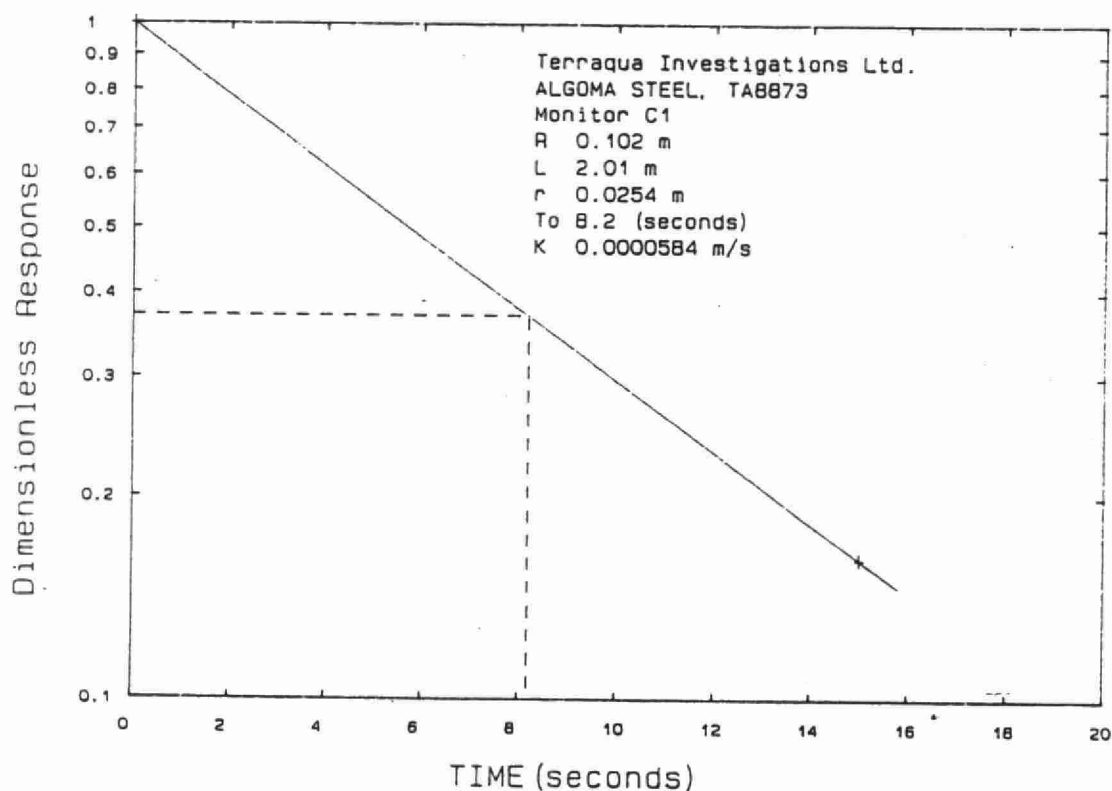


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID C1
 Static water level (mBTOP) 7.76
 Initial water level (mBTOP) 8.1
 Screen length (m) 2.01
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/18	12:53:30	0	8.10	1.000
2	88/10/18	12:53:45	15	7.81	0.162
3	88/10/18	12:54: 0	30	7.77	0.044
4	88/10/18	12:54:15	45	7.76	%-8.5599501351E-11

SLUG TEST ANALYSIS

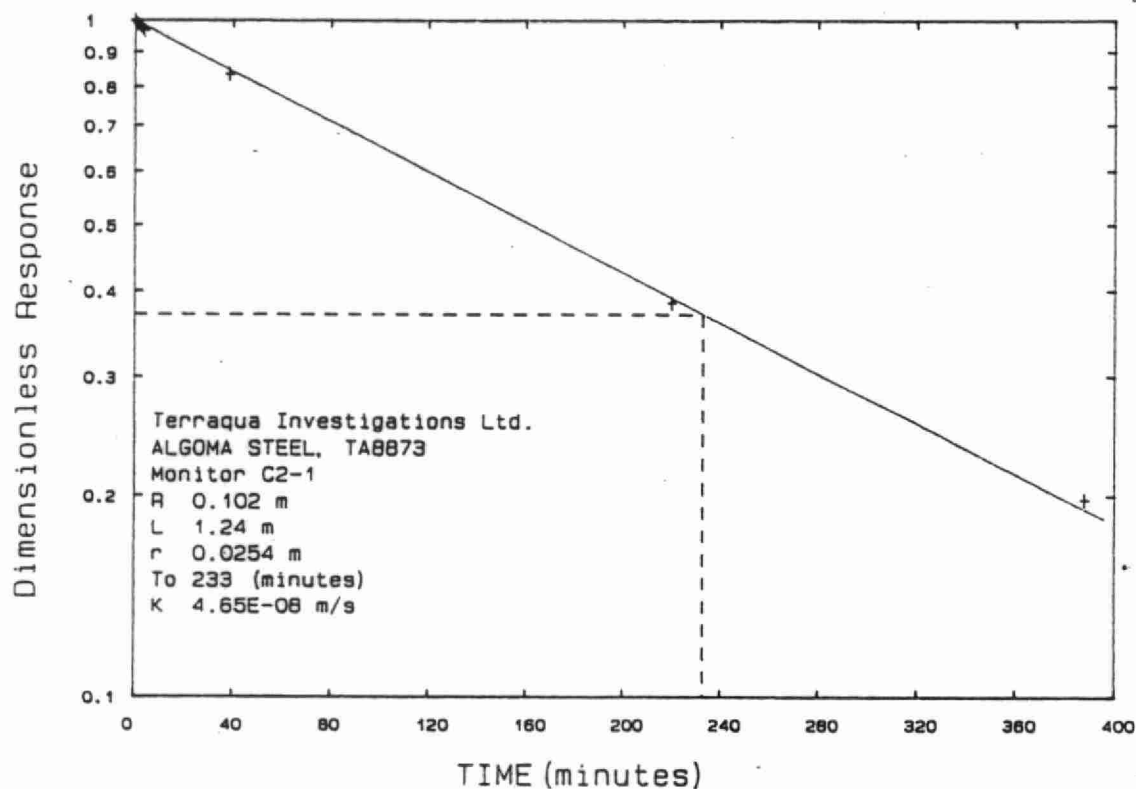


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID C2-1
 Static water level (mBTOP) 6.82
 Initial water level (mBTOP) 8.185
 Screen length (m) 1.24
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/10/18	11:17: 0	0.0	8.18	1.000
2	88/10/18	11:17:15	0.2	8.18	0.996
3	88/10/18	11:18: 0	1.0	8.17	0.989
4	88/10/18	11:19: 0	2.0	8.16	0.982
5	88/10/18	11:20: 0	3.0	8.15	0.974
6	88/10/18	11:21: 0	4.0	8.14	0.967
7	88/10/18	11:55:30	38.5	7.96	0.835
8	88/10/18	14:57: 0	220.0	7.34	0.385
9	88/10/18	17:45: 0	388.0	7.09	0.198

SLUG TEST ANALYSIS

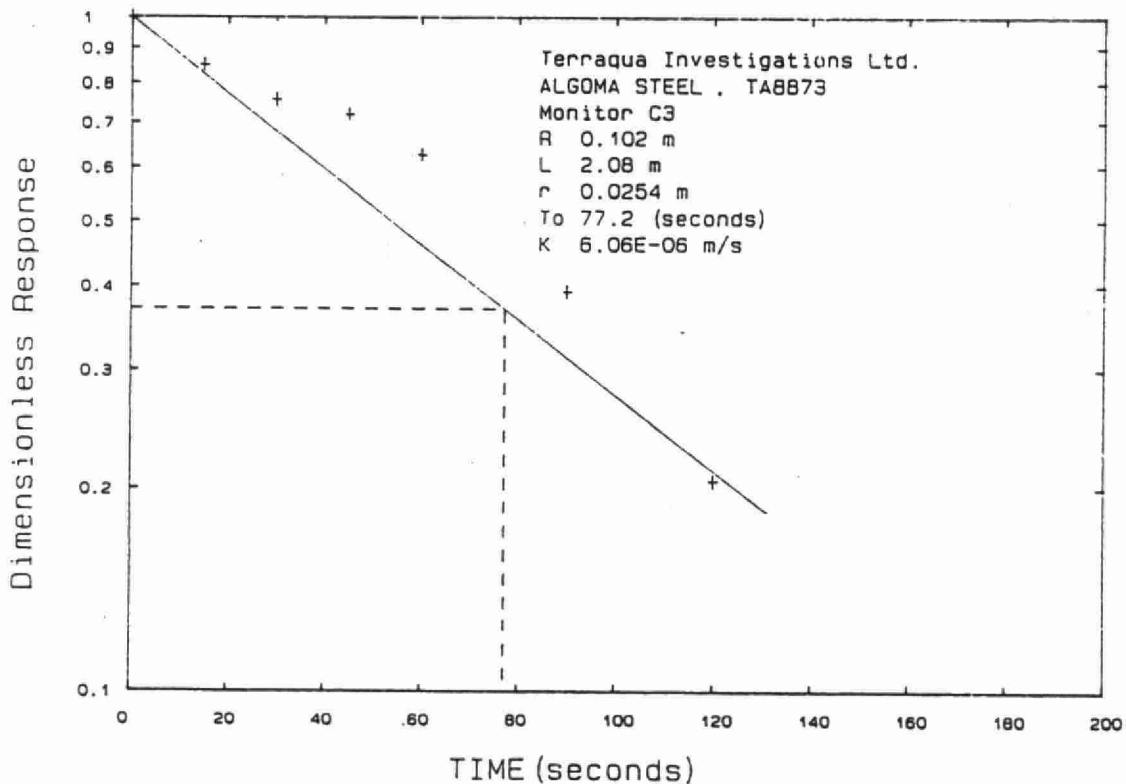


SLUG TEST DATA

Project name	ALGOMA STEEL
Project number	TA8873
Monitor ID	C3
Static water level (mBTOP)	7.045
Initial water level (mBTOP)	7.58
Screen length (m)	2.08
Screen radius (m)	0.1016
Piezometer radius (m)	0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/18	11:42: 0	0	7.58	1.000
2	88/10/18	11:42:15	15	7.50	0.850
3	88/10/18	11:42:30	30	7.45	0.757
4	88/10/18	11:42:45	45	7.43	0.720
5	88/10/18	11:43: 0	60	7.38	0.626
6	88/10/18	11:43:30	90	7.25	0.393
7	88/10/18	11:44: 0	120	7.15	0.206
8	88/10/18	11:44:30	150	7.07	0.056
9	88/10/18	11:45: 0	180	7.05	0.009

SLUG TEST ANALYSIS

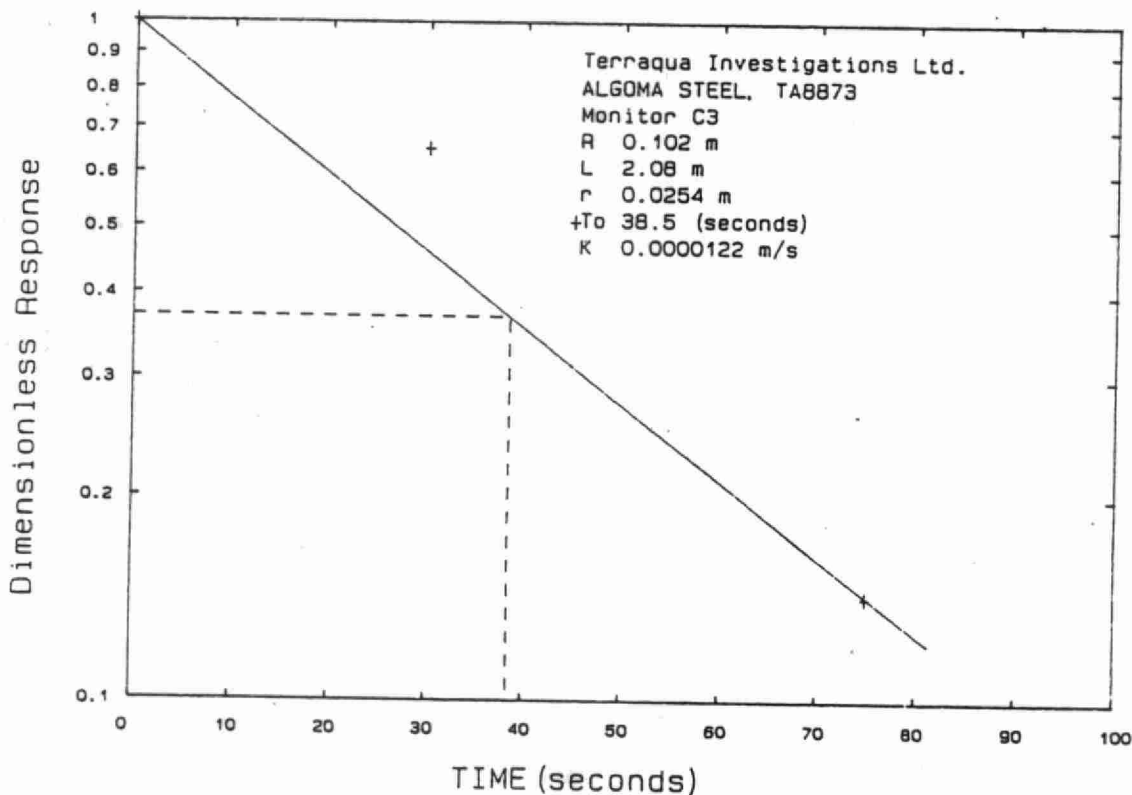


SLUG TEST DATA

Project name	ALGOMA STEEL
Project number	TA8873
Monitor ID	C3
Static water level (mBTOP)	7.045
Initial water level (mBTOP)	7.29
Screen length (m)	2.08
Screen radius (m)	0.1016
Piezometer radius (m)	0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/18	11:37:15	0	7.29	1.000
2	88/10/18	11:37:45	30	7.20	0.653
3	88/10/18	11:38: 0	45	7.17	0.510
4	88/10/18	11:38:30	75	7.08	0.143
5	88/10/18	11:39: 0	105	7.05	0.020
6	88/10/18	11:39:30	135	7.04	%-1.1879114472E-10

SLUG TEST ANALYSIS

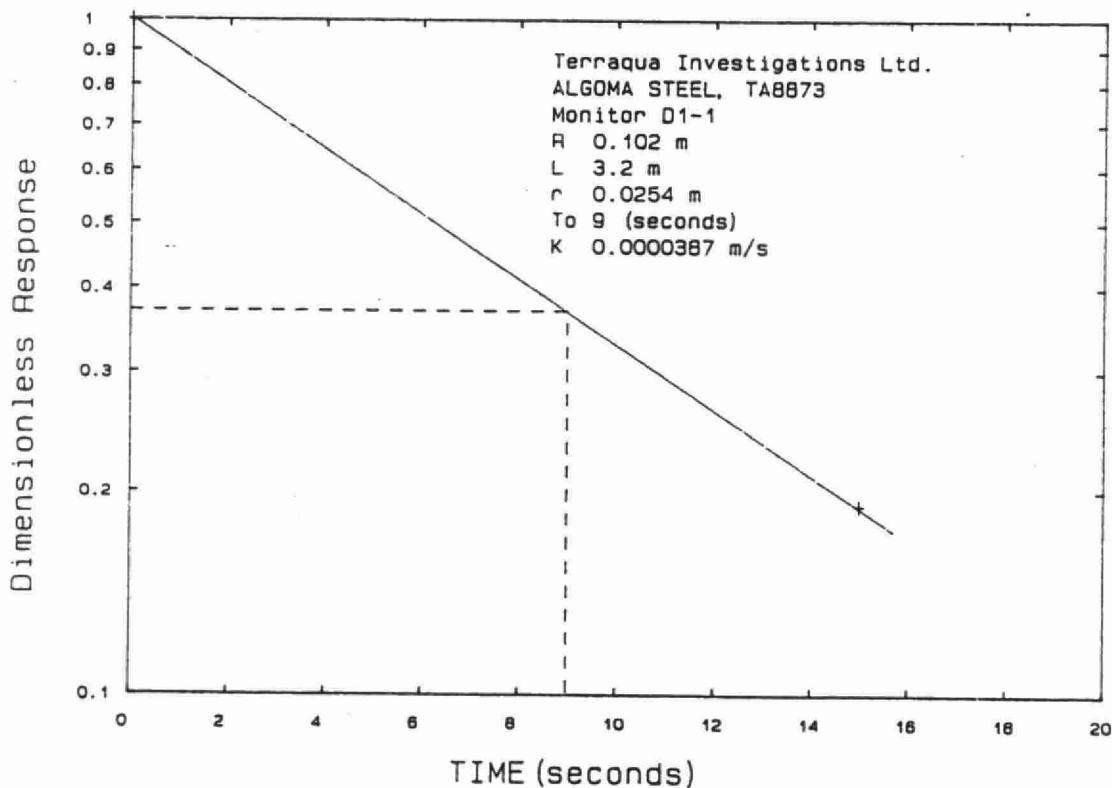


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID D1-1
 Static water level (mBTOP) 3.27
 Initial water level (mBTOP) 3.92
 Screen length (m) 3.2
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/18	15:27:30	0	3.92	1.000
2	88/10/18	15:27:45	15	3.43	0.246
3	88/10/18	15:28: 0	30	3.33	0.092
4	88/10/18	15:28:15	45	3.30	0.046
5	88/10/18	15:28:30	60	3.29	0.031
6	88/10/18	15:28:45	75	3.29	0.031
7	88/10/18	15:29: 0	90	3.29	0.031
8	88/10/18	15:40:45	795	3.27	%-2.238756189E-11

SLUG TEST ANALYSIS

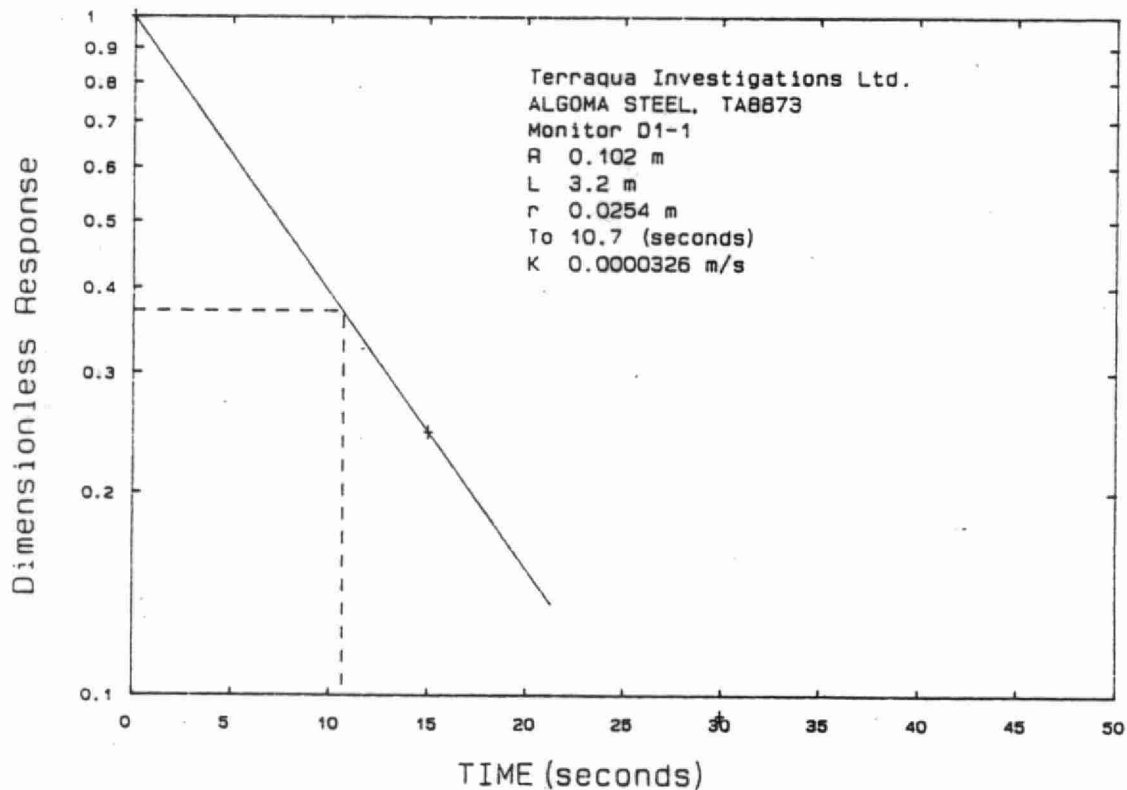


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID D1-1
 Static water level (mBTOP) 3.27
 Initial water level (mBTOP) 3.69
 Screen length (m) 3.2
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (seconds)	DEPTH TO WATER (m)	H/Ho
1	88/10/18	15:22: 0	0	3.69	1.000
2	88/10/18	15:22:15	15	3.35	0.190
3	88/10/18	15:22:30	30	3.29	0.060
4	88/10/18	15:22:45	45	3.28	0.024
5	88/10/18	15:23: 0	60	3.27	0.012

SLUG TEST ANALYSIS

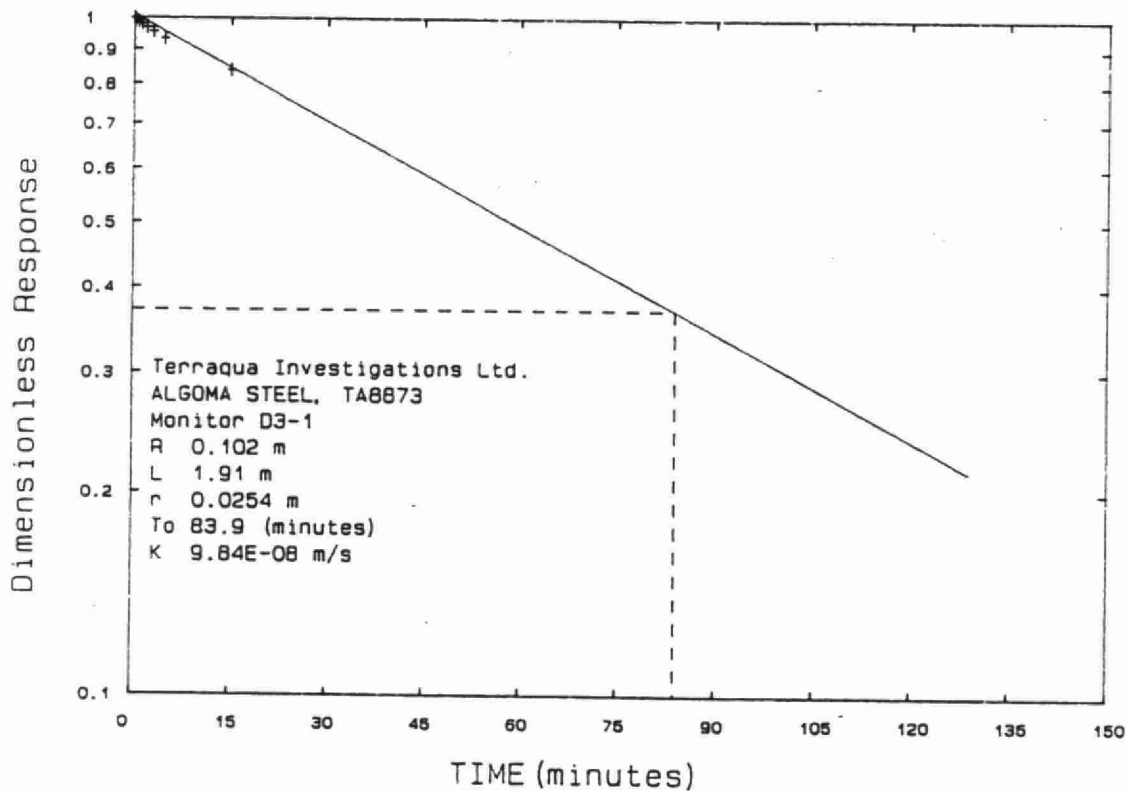


SLUG TEST DATA

Project name	ALGOMA STEEL
Project number	TA8873
Monitor ID	D3-1
Static water level (mBTOP)	2.59
Initial water level (mBTOP)	10.13
Screen length (m)	1.91
Screen radius (m)	0.1016
Piezometer radius (m)	0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	18:37:30	0.0	10.13	1.000
2	88/10/19	18:37:45	0.2	10.10	0.996
3	88/10/19	18:38:15	0.7	10.04	0.989
4	88/10/19	18:38:45	1.2	9.98	0.981
5	88/10/19	18:39:30	2.0	9.90	0.969
6	88/10/19	18:40:30	3.0	9.80	0.956
7	88/10/19	18:42:15	4.7	9.63	0.934
8	88/10/19	18:52:30	15.0	8.91	0.838
9	88/10/20	10:50:00	972.5	3.02	0.057

SLUG TEST ANALYSIS

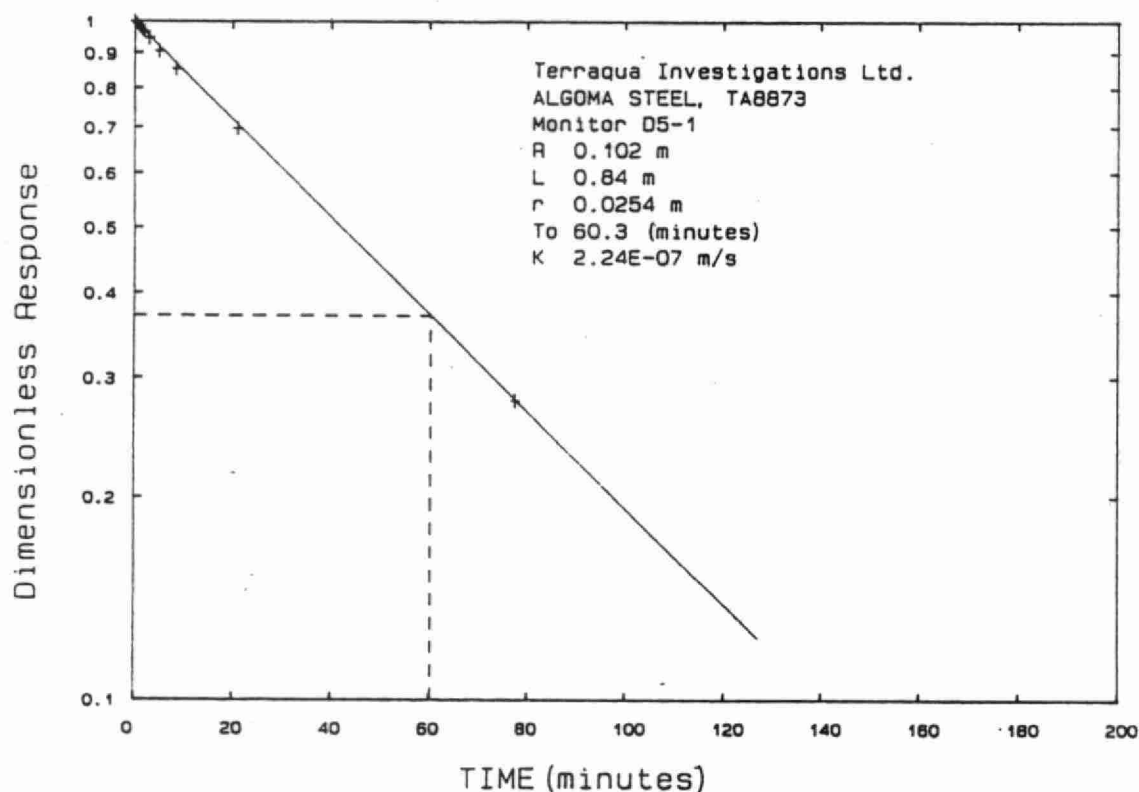


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID D5-1
 Static water level (mBTOP) 3.045
 Initial water level (mBTOP) 8.28
 Screen length (m) 0.84
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	17:40: 0	0.0	8.28	1.000
2	88/10/19	17:40:30	0.5	8.23	0.991
3	88/10/19	17:41: 0	1.0	8.18	0.982
4	88/10/19	17:41:30	1.5	8.14	0.973
5	88/10/19	17:42: 0	2.0	8.10	0.966
6	88/10/19	17:43: 0	3.0	8.00	0.947
7	88/10/19	17:45: 0	5.0	7.78	0.904
8	88/10/19	17:48:30	8.5	7.51	0.853
9	88/10/19	18: 1: 0	21.0	6.69	0.696
10	88/10/19	18:57:30	77.5	4.50	0.278
11	88/10/20	9:51: 0	971.0	3.07	0.006

SLUG TEST ANALYSIS

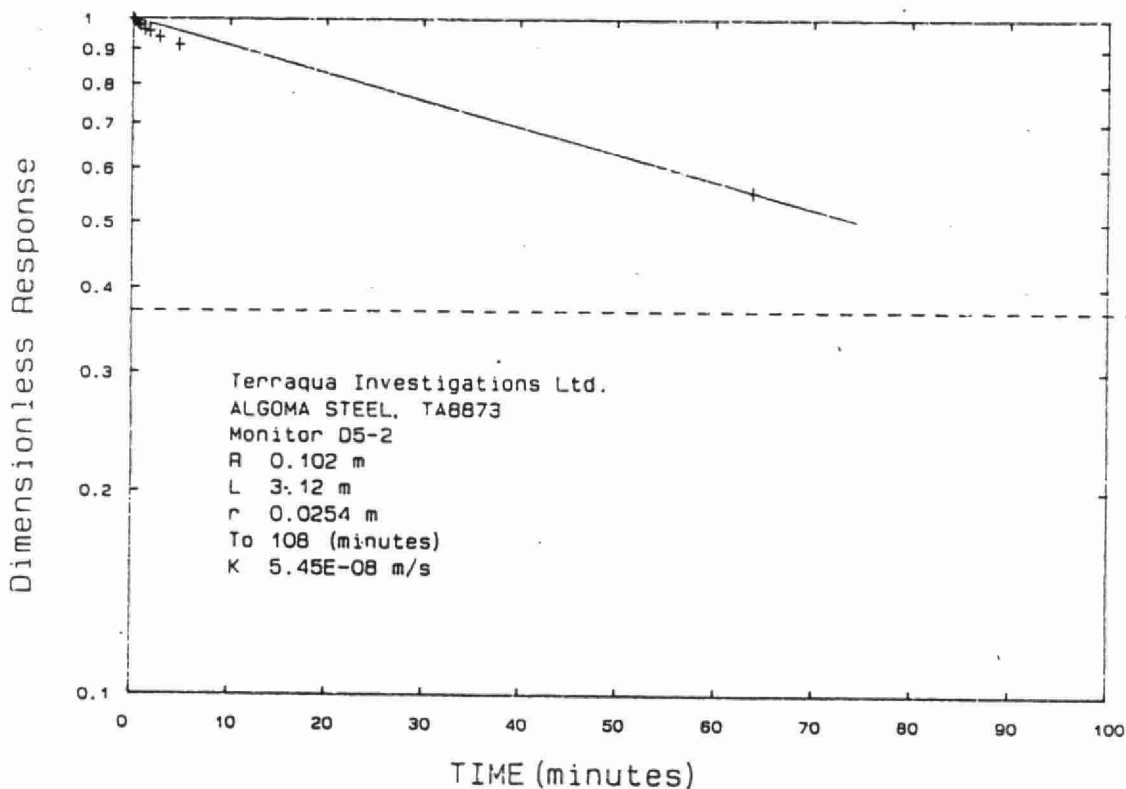


SLUG TEST DATA

Project name ALGOMA STEEL
 Project number TA8873
 Monitor ID D5-2
 Static water level (mBTOP) 3.16
 Initial water level (mBTOP) 4.77
 Screen length (m) 3.12
 Screen radius (m) 0.1016
 Piezometer radius (m) 0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	17:54:15	0.0	4.77	1.000
2	88/10/19	17:54:30	0.2	4.76	0.994
3	88/10/19	17:54:45	0.5	4.74	0.981
4	88/10/19	17:55: 0	0.7	4.73	0.975
5	88/10/19	17:55:30	1.2	4.71	0.963
6	88/10/19	17:56: 0	1.7	4.70	0.957
7	88/10/19	17:57: 0	2.7	4.67	0.938
8	88/10/19	17:59: 0	4.7	4.63	0.913
9	88/10/19	18:58: 0	63.7	4.05	0.556

SLUG TEST ANALYSIS

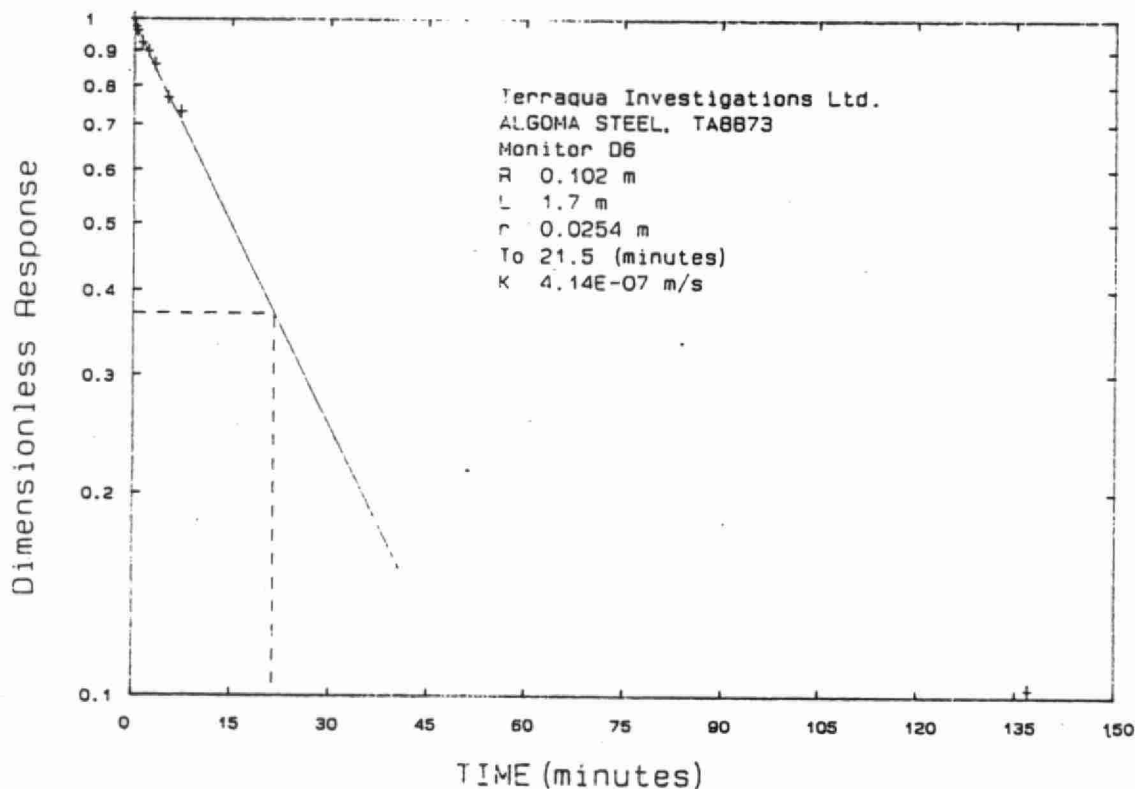


SLUG TEST DATA

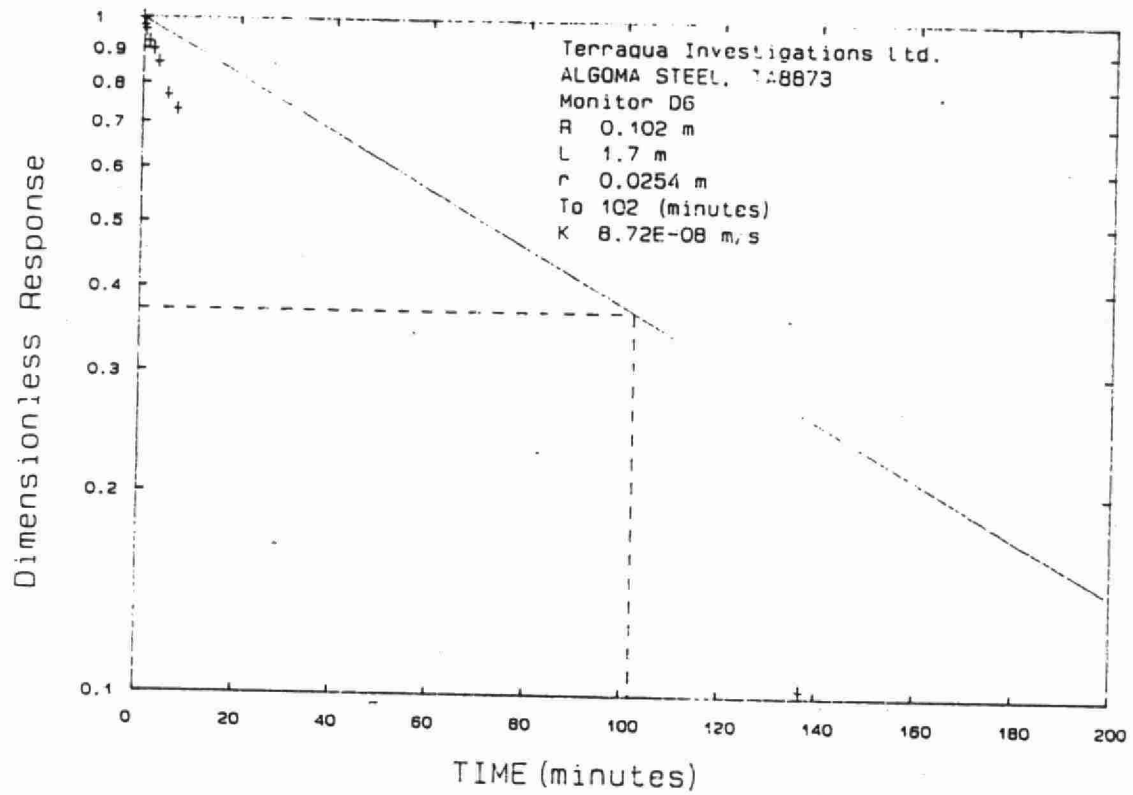
Project name	ALGOMA STEEL
Project number	TA8873
Monitor ID	D6
Static water level (mBTOP)	4.42
Initial water level (mBTOP)	4.81
Screen length (m)	1.7
Screen radius (m)	0.1016
Piezometer radius (m)	0.0254

	DATE (yy/mm/dd)	TIME (hh:mm:ss)	ELAPSED TIME (minutes)	DEPTH TO WATER (m)	H/Ho
1	88/10/19	16:44:45	0.0	4.81	1.000
2	88/10/19	16:45: 0	0.2	4.80	0.974
3	88/10/19	16:45:15	0.5	4.79	0.962
4	88/10/19	16:46: 0	1.2	4.78	0.923
5	88/10/19	16:47: 0	2.2	4.77	0.897
6	88/10/19	16:48: 0	3.2	4.75	0.859
7	88/10/19	16:50: 0	5.2	4.72	0.769
8	88/10/19	16:52: 0	7.2	4.70	0.731
9	88/10/19	19: 2: 0	137.2	4.46	0.103

SLUG TEST ANALYSIS



SLUG TEST ANALYSIS



COMPILATION OF HYDRAULIC CONDUCTIVITY DATA

Appendix 3: Compilation of Hydraulic Conductivity Data

GEOLOGIC UNIT	BOREHOLE NUMBER	TEST METHOD	ANALYSIS METHOD	HYDRAULIC CONDUCTIVITY (M/S)	LOG HYDRAULIC CONDUCTIVITY	REFERENCE
BAS SAND	A4-2	SLUG	HVORSLEV'S	1.60E-04	-3.80E+00	BEAK
BS SD/CLY	B2-1	SLUG	HVORSLEV'S	7.64E-07	-6.12E+00	BEAK
FILL - SD	OW8B-88	SLUG	HVORSLEV'S	1.40E-06	-5.85E+00	CRA 2219, 1988
FILL - SD,GVL	9-III	SLUG	HVORSLEV'S	3.00E-06	-5.52E+00	GLL 87-300, 1988
FILL - SD	OW3C-88	SLUG	HVORSLEV'S	1.80E-05	-4.74E+00	CRA 2219, 1988
FILL - COAL,SD	OW10B-88	SLUG	HVORSLEV'S	7.30E-05	-4.14E+00	CRA 2219, 1988
summary	mean			2.39E-05	-5.06E+00	
	standard deviation			2.91E-05	6.70E-01	
	mean + 1 sd			5.30E-05	-4.39E+00	
	mean - 1 sd			-5.26E-06	-5.73E+00	
FILL - SLAG	3-II	SLUG	BOUWER&RICE	9.40E-06	-5.03E+00	GLL 87-300, 1988
FILL - SLAG	5-II	SLUG	BOUWER&RICE	2.10E-05	-4.68E+00	GLL 87-300, 1988
FILL - SLAG	11-III	SLUG	BOUWER&RICE	1.70E-04	-3.77E+00	GLL 87-300, 1988
FILL - SLAG	OW9B-88	SLUG	HVORSLEV'S	2.20E-04	-3.66E+00	CRA 2219, 1988
summary	mean			1.05E-04	-4.28E+00	
	standard deviation			9.17E-05	5.84E-01	
	mean + 1 sd			1.97E-04	-3.70E+00	
	mean - 1 sd			1.34E-05	-4.87E+00	
LAM CLY/ST	11-I	SLUG	HVORSLEV'S	2.00E-09	-8.70E+00	GLL 87-300, 1988
LAM CLY/ST	6-I	SLUG	HVORSLEV'S	3.90E-09	-8.41E+00	GLL 87-300, 1988
LAM CLY/ST	1-I	SLUG	HVORSLEV'S	4.80E-09	-8.32E+00	GLL 87-300, 1988
LAM CLY/ST	9-I	SLUG	HVORSLEV'S	8.20E-09	-8.09E+00	GLL 87-300, 1988
LAM CLY/ST	OW3A-88	SLUG	HVORSLEV'S	1.40E-08	-7.85E+00	CRA 2219, 1988
LAM CLY/ST	A7-2 LATE	SLUG	HVORSLEV'S	5.12E-08	-7.29E+00	BEAK
LAM CLY/ST	B4-1	SLUG	HVORSLEV'S	2.03E-07	-6.69E+00	BEAK
LAM CLY/ST	OW13A-88	SLUG	HVORSLEV'S	3.70E-07	-6.43E+00	CRA 2219, 1988
LAM CLY/ST	B4-1 REP	SLUG	HVORSLEV'S	4.18E-07	-6.38E+00	BEAK
summary	mean			1.19E-07	-7.57E+00	
	standard deviation			1.59E-07	8.46E-01	
	mean + 1 sd			2.78E-07	-6.73E+00	
	mean - 1 sd			-3.95E-08	-8.42E+00	
ORG SILT	A4-1	SLUG	HVORSLEV'S	1.65E-06	-5.78E+00	BEAK
ORG SILT	A5	SLUG	HVORSLEV'S	1.98E-06	-5.70E+00	BEAK
ORG SILT	A3 LATE	SLUG	HVORSLEV'S	4.93E-06	-5.31E+00	BEAK
ORG SILT	A3 EARLY	SLUG	HVORSLEV'S	3.21E-05	-4.49E+00	BEAK
summary	mean			1.02E-05	-5.32E+00	
	standard deviation			1.27E-05	5.11E-01	
	mean + 1 sd			2.29E-05	-4.81E+00	
	mean - 1 sd			-2.56E-06	-5.83E+00	
SAND	A6 LATE	SLUG	HVORSLEV'S	1.19E-06	-5.92E+00	BEAK
SAND	OW5-88	SLUG	HVORSLEV'S	1.20E-05	-4.92E+00	CRA 2219, 1988
SAND	D1-1 REP	SLUG	HVORSLEV'S	3.26E-05	-4.49E+00	BEAK
SAND	OW7A-88	SLUG	HVORSLEV'S	3.30E-05	-4.48E+00	CRA 2219, 1988
SAND	D1-1	SLUG	HVORSLEV'S	3.87E-05	-4.41E+00	BEAK
SAND	OW2-88	SLUG	HVORSLEV'S	4.10E-05	-4.39E+00	CRA 2219, 1988
SAND	OW10A-88	SLUG	HVORSLEV'S	8.50E-05	-4.07E+00	CRA 2219, 1988
SAND	9-II	SLUG	HVORSLEV'S	9.00E-05	-4.05E+00	GLL 87-300, 1988
SAND	OW6-88	SLUG	HVORSLEV'S	9.50E-05	-4.02E+00	CRA 2219, 1988
SAND	OW3B-88	SLUG	HVORSLEV'S	1.00E-04	-4.00E+00	CRA 2219, 1988
SAND	OW12A-88	SLUG	HVORSLEV'S	1.00E-04	-4.00E+00	CRA 2219, 1988
SAND	OW13B-88	SLUG	HVORSLEV'S	1.90E-04	-3.72E+00	CRA 2219, 1988
SAND	OW9A-88	SLUG	HVORSLEV'S	2.60E-04	-3.59E+00	CRA 2219, 1988
SAND	OW4A-88	SLUG	HVORSLEV'S	2.90E-04	-3.54E+00	CRA 2219, 1988
SAND	7-I	SLUG	HVORSLEV'S	2.90E-04	-3.54E+00	GLL 87-300, 1988
SAND	OW8A-88	SLUG	HVORSLEV'S	4.10E-04	-3.39E+00	CRA 2219, 1988
SAND	1-II	SLUG	HVORSLEV'S	4.10E-04	-3.39E+00	GLL 87-300, 1988

Appendix 3: Compilation of Hydraulic Conductivity Data

GEOLOGIC UNIT	BOREHOLE NUMBER	TEST METHOD	ANALYSIS METHOD	HYDRAULIC CONDUCTIVITY (M/S)	LOG HYDRAULIC CONDUCTIVITY	REFERENCE
SAND summary	OW1A-88 mean standard deviation mean + 1 sd mean - 1 sd	SLUG	HVORSLEV'S	6.40E-04 1.73E-04 1.71E-04 3.44E-04 2.10E-06	-3.19E+00 -4.06E+00 6.39E-01 -3.42E+00 -4.70E+00	CRA 2219, 1988
STY SAND	C2-1	SLUG	HVORSLEV'S	4.65E-08	-7.33E+00	BEAK
STY SAND	A1-2 LATE	SLUG	HVORSLEV'S	1.63E-06	-5.79E+00	BEAK
STY SAND	A2-2 LATE	SLUG	HVORSLEV'S	5.25E-06	-5.28E+00	BEAK
STY SAND summary	A1-2 EARLY mean standard deviation mean + 1 sd mean - 1 sd	SLUG	HVORSLEV'S	2.92E-05 9.03E-06 1.18E-05 2.08E-05 -2.76E-06	-4.53E+00 -5.73E+00 1.03E+00 -4.71E+00 -6.76E+00	BEAK
TILL	D3-1	SLUG	HVORSLEV'S	9.84E-08	-7.01E+00	BEAK
TILL	D5-1	SLUG	HVORSLEV'S	2.24E-07	-6.65E+00	BEAK
TILL	A1-1 LATE	SLUG	HVORSLEV'S	9.25E-07	-6.03E+00	BEAK
TILL summary	A1-1 EARLY mean standard deviation mean + 1 sd mean - 1 sd	SLUG	HVORSLEV'S	1.01E-05 2.84E-06 4.21E-06 7.04E-06 -1.37E-06	-5.00E+00 -6.17E+00 7.63E-01 -5.41E+00 -6.93E+00	BEAK
BEDROCK	A2-1	SLUG	HVORSLEV'S	6.17E-09	-8.21E+00	BEAK
BEDROCK	4 38.2-43.2	PUMP-IN PACKER		6.90E-08	-7.16E+00	GEOCON
BEDROCK	2 31.5-41.5	FALLING HEAD		2.10E-07	-6.68E+00	GEOCON
BEDROCK	1 35-40.5'	PUMP-IN PACKER		4.70E-07	-6.33E+00	GEOCON
BEDROCK	1 40.0-45.5	PUMP-IN PACKER		6.30E-07	-6.20E+00	GEOCON
BEDROCK	4 30.2-43.2	FALLING HEAD		8.20E-07	-6.09E+00	GEOCON
BEDROCK	9 43.0-49.0	FALLING HEAD		1.20E-06	-5.92E+00	GEOCON
BEDROCK	2 31.5-36.5	PUMP-IN PACKER		1.30E-06	-5.89E+00	GEOCON
BEDROCK	2 21.7-39.3	FALLING HEAD		3.00E-06	-5.52E+00	GEOCON
BEDROCK	1 25-45.5'			3.80E-06	-5.42E+00	GEOCON
BEDROCK	4 27.0-32.0	PUMP-IN PACKER		4.30E-06	-5.37E+00	GEOCON
BEDROCK	2 21.7-30.6	FALLING HEAD		6.10E-06	-5.21E+00	GEOCON
BEDROCK	2 21.7-25.6	FALLING HEAD		8.50E-06	-5.07E+00	GEOCON
BEDROCK	1 25-35.5'			8.80E-06	-5.06E+00	GEOCON
BEDROCK	1 25-30.5'	FALLING HEAD		9.60E-06	-5.02E+00	GEOCON
BEDROCK	4 24.0-29.0	PUMP-IN PACKER		1.20E-05	-4.92E+00	GEOCON
BEDROCK	2 24.6-29.6	PUMP-IN PACKER		1.40E-05	-4.85E+00	GEOCON
BEDROCK	4 33.0-38.0	PUMP-IN PACKER		1.60E-05	-4.80E+00	GEOCON
BEDROCK summary	mean standard deviation mean + 1 sd mean - 1 sd			5.04E-06 5.07E-06 1.01E-05 -2.90E-08	-5.76E+00 8.84E-01 -4.88E+00 -6.65E+00	

Data Sources:

Beak, Appendix 3
Conestoga Rovers Assoc., 1988
Gartner Lee Ltd., 1988
Geocon, 1983

APPENDIX 4

Leach Test Data

SUMMARY OF CSEA* LEACHATE ANALYSES FOR ALGOMA

Parameter	BOSP Filter Cake	BF Slag	BF Filter Cake	No. 2 BOSP Slag Fines IMS Plant	Waste Lime	Regulation 309 Schedule 5 (Appendix IV)	MOE Drinking Water Criteria
Free CN ⁻	L 0.005	0.013	0.020	L 0.005	0.007	0.20	0.20
Phenols	0.011	0.006	0.008	0.010	0.008	-	0.001
TOC	2.5	1.0	2.5	5.0	3.0	-	5.0
As	L 0.001	L 0.001	0.010	L 0.001	L 0.001	0.05	0.01
Se	L 0.001	0.003	0.004	L 0.001	L 0.001	0.01	0.01
Cd	L 0.0005	L 0.0005	L 0.0005	L 0.0005	L 0.0005	0.005	0.01
Ag	0.017	L 0.005	L 0.005	0.006	0.045	0.05	0.05
Al	L 0.01	0.44	1.08	0.44	L 0.01	-	-
B	0.152	0.096	0.178	0.063	0.076	5.0	-
Ba	0.267	0.144	0.151	0.132	0.086	1.0	1.0
Be	L 0.0005	L 0.0005	L 0.0005	L 0.0005	L 0.0005	-	-
Ca	419	50	21.4	226	1,230	-	-
Co	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	-	-
Cr	L 0.01	L 0.01	L 0.01	L 0.01	0.03	0.05	-
Cr ⁺⁶	L 0.002	L 0.002	L 0.002	L 0.002	L 0.002	-	0.05
Cu	0.015	L 0.008	0.008	0.018	0.030	-	1.0
Fe	0.03	L 0.01	0.02	0.02	0.06	-	0.30
Hg	L 0.00002	L 0.00002	L 0.00002	L 0.00002	L 0.00002	0.001	-
K	1	1	2	L 1	449	-	-
Mg	L 0.01	2.08	1.02	L 0.01	L 0.01	-	-
Mn	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	-	0.05
Mo	0.2	L 0.2	L 0.2	L 0.2	L 0.2	-	-
Na	3	2	2	1	107	-	-
Ni	L 0.05	L 0.05	L 0.05	L 0.05	0.06	-	-
P	L 0.6	L 0.6	L 0.6	L 0.6	L 0.6	-	-
Pb	0.005	L 0.001	L 0.001	L 0.001	0.005	0.05	0.05
Si	0.52	6.02	2.76	3.24	0.19	-	-
Sr	0.115	0.057	0.023	0.017	2.60	-	-
Th	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	-	-
Ti	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	-	-
V	L 0.005	L 0.005	0.007	0.009	L 0.005	-	-
Zn	0.08	L 0.05	L 0.05	L 0.05	0.07	-	5
Zr	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	-	-
F ⁻	1.14	0.14	0.72	0.68	1.98	2.4	-
Cl ⁻	1.38	0.18	1.04	0.49	449	-	50
PO ₄ ⁻³	L 0.1	L 0.1	L 0.1	L 0.1	L 1	-	-
NO ₃ ⁻	2.03	L 0.05	L 0.05	0.20	L 0.50	10	10
SO ₄ ⁼	4.08	92	36.3	4.75	74.6	-	250

Concentration units are mg/L.

* Canadian Steel Environmental Association (1983).

Sample ID	A1	A2	A7	B4	C4	D3	RS-1	RS-2	RS-6	RS-7	RS-9	RS-9	RS-10	RS-10	RS-11
Leach Type	Reg. 309	Reg. 309	Alkaline	Alkaline	Alkaline	Alkaline	Reg. 309	HCl	HCl	HCl	HCl	Alkaline	HCl	Alkaline	Reg. 309
Acetic Acid (mL/g)	0	1.45	-	-	-	-	1.94	-	-	-	-	-	-	-	0.12
0.5N HCL Solution (mL)	-	-	-	-	-	-	-	4.0	4.0	0.80	4.0	-	0.33	-	-
Moisture (%)	16.7	47	26	22	41	19.5	2.6	33	2.5	1.4	25	25	5.8	5.8	2.3
0.5N NaOH Solution (mL)	-	-	0.02	0.04	0	0	-	-	-	-	-	0	-	0.02	-
Final pH	4.39	5.01	10.25	10.29	12.30	11.48	5.14	5.51	11.03	6.65	7.23	11.63	6.43	10.10	5.06
Initial pH	4.03	6.47	9.54	9.38	12.16	11.44	8.74	7.01	12.18	10.02	11.23	11.35	8.74	9.5	9.51
Phenols	0.060	0.005	0.008	0.005	0.062	0.011	0.032	<0.001	0.002	<0.001	<0.001	0.001	1.66	2.5	0.001
Oil and Grease	-	-	2	<2	-	-	-	-	<2	<2	-	-	-	-	-
Sulphide	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05	-	0.51	-
Total Cyanide	-	-	-	-	0.006	<0.002	-	0.075	-	-	0.066	0.009	0.039	5.5	-
Bromide	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5/<0.5	<0.5	<0.5	<0.5	<0.5
Chloride	7.5	3.3	5.2	1.5	5.7	2.2	6.3	-	-	-	-	1.40	-	2.7/2.7	5.4
Fluoride	-	-	0.13/0.12	0.04	0.52	0.48	-	1.21	1.38	1.9	6.9/7.3	1.90	0.25	0.39	-
Nitrate-N	<0.1	<0.1	0.10	0.20	0.10	1.10	<0.1	0.10	0.50	<0.1	0.50/<0.1	1.10	0.50	0.20/0.20	<0.1
Total Kjeldahl Nitrogen	1.0	2.2	-	-	0.79	2.2	1.19	2.3	-	-	0.90/0.61	0.33	2.7	8.4	0.53
Sulphate	195	300	5.0	1.5	1.5	8.0	21/20	575	250	11.5	39/40	6.0	1.5	13.5/13.5	0.25
Zinc	0.01	0.03	<0.01	<0.01	0.02	0.04	0.36/0.48	0.09	0.03	0.02	0.08/0.10	0.03	0.48	<0.01	0.25
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005/<0.005	<0.005	<0.005	<0.005	<0.005/<0.005	<0.005	<0.005	<0.005	<0.005
Manganese	14.6	36	<0.01	<0.01	<0.01	<0.01	29/32	35	0.01	6.1	5.0/5.6	<0.01	1.42	<0.01	0.44
Cobalt	<0.01	0.05	<0.01	<0.01	0.02	<0.01	0.02/0.03	0.17	0.08	0.03	0.06/0.06	0.01	<0.01	<0.01	<0.01
Copper	0.010	0.010	<0.005	<0.005	0.035	0.055	0.020/0.010	0.020	0.015	0.005	0.025/0.030	0.020	0.020	<0.005	0.005
Iron	8.1	0.78	0.04	0.02	<0.02	0.02	1.66/2.9	330/330	0.04	0.02	0.04/0.06	<0.02	60	0.42	0.04
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05/<0.05	<0.05	<0.05	<0.05	0.10/0.10	<0.05	7.8	<0.05	<0.05
Chromium	<0.01	0.01	<0.01	<0.01	0.03	<0.01	0.03/0.04	0.16	0.15	0.03	0.07/0.07	0.01	0.08	<0.01	<0.01
Nickel	<0.01	0.02	<0.01	<0.01	0.03	<0.01	0.03/0.04	0.41	0.06	0.02	0.08/0.09	<0.01	0.79	<0.01	<0.01
Beryllium	<0.01	<0.01	-	-	<0.01	<0.01	<0.01/<0.01	<0.01	-	-	<0.01/<0.01	<0.01	<0.01	<0.01	<0.01
Molybdenum	0.02	<0.02	-	-	0.02	<0.02	<0.02/<0.02	0.06	-	-	0.06/0.08	<0.02	<0.02	0.04	<0.02
Calcium	14.3	390	-	-	-	-	560/670	3600	-	-	1530/1520	-	31	-	38
Vanadium	<0.01	0.03	-	-	0.04	0.01	0.06/0.07	0.15	-	-	0.07/0.08	0.01	<0.01	<0.01	<0.01
Aluminum	2.2	0.86	-	-	0.64	4.4	17.3/2.7	1.10	-	-	0.66/0.76	0.48	0.14	0.24	0.08
Magnesium	26	92	-	-	0.25	0.05	75/64	750	-	-	450/450	0.05	2.6	0.20	3.4
Barium	0.02	0.18	-	-	0.37	0.17	0.54/0.69	0.10	-	-	0.07/0.11	0.04	0.10	<0.01	0.28
Potassium	8.5	9.2	-	-	2.2	5.4	3.3/3.8	16.8	-	-	2.8/2.4	2.2	0.45	0.55	0.45
Strontium	0.06	1.01	-	-	0.18	0.19	0.49/0.55	1.19	-	-	0.66/0.64	0.14	0.04	0.01	0.20
Sodium	7.5	13.5	-	-	13.0	8.5	21/12.0	44	-	-	20/22	3.5	5.5	10.0	10.5
PAHs (ug/L)															
Naphthalene	375	0.7	-	-	>500	1.5	>500	0.7	-	-	0.9/0.2	3.6	>500	>500	0.8
Acenaphthylene	0.2	<0.2	-	-	38	<0.2	28	<0.2	-	-	<0.2	0.9	288	96	2.2
Acenaphthene	<0.2	<0.2	-	-	1.0	<0.2	5.2	<0.2	-	-	<0.2	1.8	4.2	1.7	<0.2
Fluorene	0.5	<0.2	-	-	3.6	<0.2	3.8	<0.2	-	-	<0.2	17	22	7.1	<0.2
Phenanthrene	<0.2	<0.2	-	-	2.7	0.3	2.7	0.5	-	-	<0.2	49	20	6.3	<0.2
Anthracene	<0.2	<0.2	-	-	<0.2	<0.2	1.3	<0.2	-	-	<0.2	1.1	5.2	1.3	<0.2
Fluoranthene	<0.2	<0.2	-	-	<0.2	<0.2	0.6	0.3	-	-	<0.2	2.9	1.7	0.9	<0.2
Pyrene	<0.2	<0.2	-	-	<0.2	<0.2	0.6	<0.2	-	-	<0.2	4.1	0.9	0.3	<0.2
Benzo(a)anthracene	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	-	-	<0.2	1.4	<0.2	0.2	<0.2
Chrysene	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	-	-	<0.2	4.3	<0.2	<0.2	<0.2
Benzo(b)fluoranthene	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	-	-	<0.2	2.3	<0.2	<0.2	<0.2
Benzo(k)fluoranthene	*	*	-	-	*	*	*	*	-	-	*	*	*	*	*
Benzo(a)pyrene	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	-	-	<0.2	0.5	<0.2	<0.2	<0.2
Perylene	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	<0.2
Indeno(1,2,3-c,d)pyrene	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	<0.2
Dibenzo(a,h)anthracene	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	<0.2
Benzo(g,h,i)perylene	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	-	-	<0.2	<0.2	<0.2	<0.2	<0.2
Total PAHs	375.7	0.7	-	-	>545.3	1.8	>542.3	1.5	-	-	0.4	88.9	>842	>613.8	3

* Benzo(b)fluoranthene = (Benzo(b)fluoranthene + Benzo(k)fluoranthene)



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